AP402

AIR POLLUTION
ENGINEERING MANUAL

SECOND EDITION

Compiled and Edited
by
John A. Danielson

AIR POLLUTION CONTROL DISTRICT
COUNTY OF LOS ANGELES

The AP series of reports is published by the Technical Publications Branch of the Information Services Division of the Office of Administration for the Office of Air and Water Programs, Environmental Protection Agency, to report the results of scientific and engineering studies, and information of general interest in the field of air pollution. Information reported in this series includes coverage of intramural activities and of cooperative studies conducted in conjunction with state and local agencies, research institutes, and industrial organizations. Copies of AP reports are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations - as supplies permit - from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711 or from the Superintendent of Documents.

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FOREWORD

As concern for the quality of the atmosphere has grown, so also has the response to that concern. Federal, State, and local programs are assuming increasingly greater responsibility in the development and practice of the many disciplines that contribute to understanding and resolution of the air pollution problem.

Rapid program expansion imposes even greater demands for the dissemination of knowledge in the field of air pollution control. Much work has been accomplished by competent scientists and engineers. However, in many instances, the experience gained has not been transcribed and organized into a form readily accessible to those most in need of information.

We are pleased, therefore, to have the opportunity to make available this second edition of the Air Pollution Engineering Manual. Distilling as it does the equivalent of hundreds of man-years of painstaking engineering innovation in the air pollution control field under one cover, it has become a valuable—if not indispensable—tool.

The manual is an outgrowth of the practical knowledge gained by the technical personnel of the Los Angeles County Air Pollution Control District, long recognized as outstanding in the field. District personnel have worked closely with industry to develop emission controls where none formerly existed.

It will be noted that there are categories of industrial emissions that are not discussed. The reason is that engineering control applications are described for only those industries located in Los Angeles County.

Realizing the value of this manual to the field of air pollution, Mr. Robert L. Chass, Air Pollution Control Officer of Los Angeles County, has authorized the up-dating of the manual into this second edition. The editorial and technical content were developed exclusively by the District. The staff, in turn, was supervised during the development of the manual by Mr. Robert G. Lunche, Chief Deputy Air Pollution Control Officer, and Mr. Eric Lemke, Director of Engineering. Mr. John A. Danielson, Senior Air Pollution Engineer, has again served as editor.

The Environmental Protection Agency, recognizing the need for such a manual, is pleased to serve as publisher.

PREFACE

The first edition of the Air Pollution Engineering Manual was acknowledged by its readers to be an outstanding and practical manual on the control of air pollution. It has been in wide demand throughout the United States and in many other parts of the world. Recognizing the need for an up-dated version, Editor John A. Danielson and the engineers of the Los Angeles County Air Pollution Control District have prepared this second edition.

The first edition was written in the early sixties. Since that time, many changes have occurred in the field of air pollution control, and this second edition reflects these changes. The control of photochemically reactive organic solvent emissions is but one example, and a new chapter is devoted to this subject. Reducing the formation of oxides of nitrogen in combustion processes by improved burner and furnace designs is another new innovation. Improved versions of afterburner control devices are included. This second edition also contains a comprehensive index to aid the reader in locating quickly the subject of his choice.

The manual deals with the control of air pollution at specific sources. This approach emphasizes the practical engineering problems of design and operation associated with the many sources of air pollution. These sources include metallurgical, mechanical, incineration, combustion, petroleum, chemical, and organic-solvent-emitting processes.

The manual consists of 12 chapters, each by different authors, and 5 appendices. The first five chapters treat the history of air pollution in Los Angeles County, the types of contaminants, and the design of air pollution control devices. The remaining chapters discuss the control of air pollution from specific sources. A reader interested in controlling air pollution from a specific source can gain the information needed by referring only to the chapter of the manual dealing with that source. If he then desires more general information about an air pollution control device, he can refer to other chapters. It is suggested that Chapter 1 be read since it cites Los Angeles County prohibitory rules that regulated the degree of control efficiency required when the manual was written in 1971.

It is recognized that air pollution problems of one area can be quite different from those of another area. The air pollution problems presented in this manual originate in industrial and commercial sources in the Los Angeles area. Consequently, some processes, e.g., the burning of coal in combustion equipment, are not mentioned. Furthermore, the degree of air pollution control strived for in this manual corresponds to the degree of control demanded by air pollution statutes of the Los Angeles County Air Pollution Control District. Many other areas require less stringent control and permit less efficient control devices.

Sole responsibility for the information is borne by the District, which presents this second edition of the manual for the advancement of national understanding of the control of air pollution from stationary sources.

Robert L. Chass

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Air Pollution Control Officer
County of Los Angeles

ACKNOWLEDGMENT

CHAPTER 6

METALLURGICAL EQUIPMENT

FURNACE TYPES

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STEEL-MANUFACTURING PROCESSES

WILLIAM F. HAMMOND, Senior Air Pollution Engineer

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IRON CASTING

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SECONDARY BRASS- AND BRONZE-MELTING PROCESSES

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SECONDARY ZINC-MELTING PROCESSES

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METALLURGICAL EQUIPMENT

Efficient control of air contaminants from metallurgical furnaces has been achieved only in recent years. Since most of these furnaces discharge high-temperature effluents containing submicron-size dusts and fumes, these effluents must sometimes be cooled and often further conditioned before ducting to a control device. The control device must be one capable of high-efficiency collection of submicron particles.

This chapter discusses these control devices and the air pollution problems encountered in steel, iron, brass, aluminum, zinc, lead, and metal separation processes. Processes related to metallurgical operations such as manufacture of sand cores, foundry sand-handling equipment, and heat treating systems will be discussed near the end of this chapter.

For those not acquainted with the many types of melting furnaces, the first part of this chapter describes briefly the more common furnaces and their principles of operation. The air pollution aspects of these furnaces are not discussed immediately since these problems are usually a function of the specific melting process and not of the type of furnace used.

FURNACE TYPES

REVERBERATORY FURNACE

A reverberatory furnace operates by radiating heat from its burner flame, roof, and walls onto the material heated. This type of furnace was developed particularly for melting solids and for refining and heating the resulting liquids. It is generally one of the least expensive methods for melting since the flame and products of combustion come in direct contact with the solid and molten metal. The reverberatory furnace usually consists of a shallow, generally rectangular, refractory hearth for holding the metal charge. The furnace is enclosed by vertical side walls and covered with a low, arched, refractory-lined roof. Combustion of fuel occurs directly above the molten bath; the walls and roof receive radiant heat from the hot combustion products and, in turn, reradiate this heat to the surface of the bath. Transfer of heat is accomplished almost entirely by radiation.

Reverberatory furnaces are available in many types and designs, depending upon specific job require-

ments. Probably the largest of the reverberatory furnaces is the open-hearth furnace, widely used in the manufacture of steel. This furnace operates in conjunction with two heat regenerators consisting of brick checkerwork; these remove the heat from the effluent and transfer it to the incoming air (Figure 159). The transfer is accomplished by a system of butterfly valves, which allows the furnace gases to pass through one set of checkerwork, giving up heat, while the incoming combustion air passes through the second set of checkerwork, taking up heat. Periodically the valves are reversed, which allows incoming combustion air to preheat in the first set of checkerwork while the furnace gases are heating the second regenerator. The charge is introduced through refractory-lined doors in the front wall; finished steel and slag are removed through a taphole in the rear wall. Heat is provided by passing a luminous flame with excess air over the charged material. Details of operation in the production of steel with the open-hearth furnace are described later in this chapter.
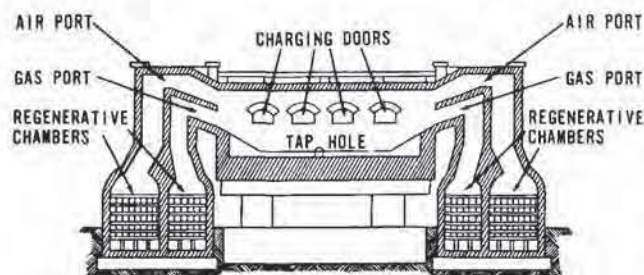
Figure 159. An open-hearth furnace (Begeman, 1947).

Another type of reverberatory furnace is the cylindrical furnace, commonly used in the nonferrous industries for melting and holding small heats of aluminum, brass, and various alloys. Cylindrical reverberatory furnaces are relatively small, usually rated at 500 pounds of aluminum. These furnaces (Figure 160) are fired through two tangential nozzles that promote excellent combustion characteristics and provide very rapid melting. The furnace may be charged through a top opening or through the end door. The end door also serves as an access to the metal bath for adding alloying materials or drossing.

Reverberatory furnace designs often use rotary tilting mechanisms. A tilting furnace promotes ease of metal distribution for all types of casting

Figure 160. Gas-fired, cylindrical reverberatory furnace (Bulletin No. 6011, Hevi-Duty Heating Equipment Co., Watertown, Wisc.).

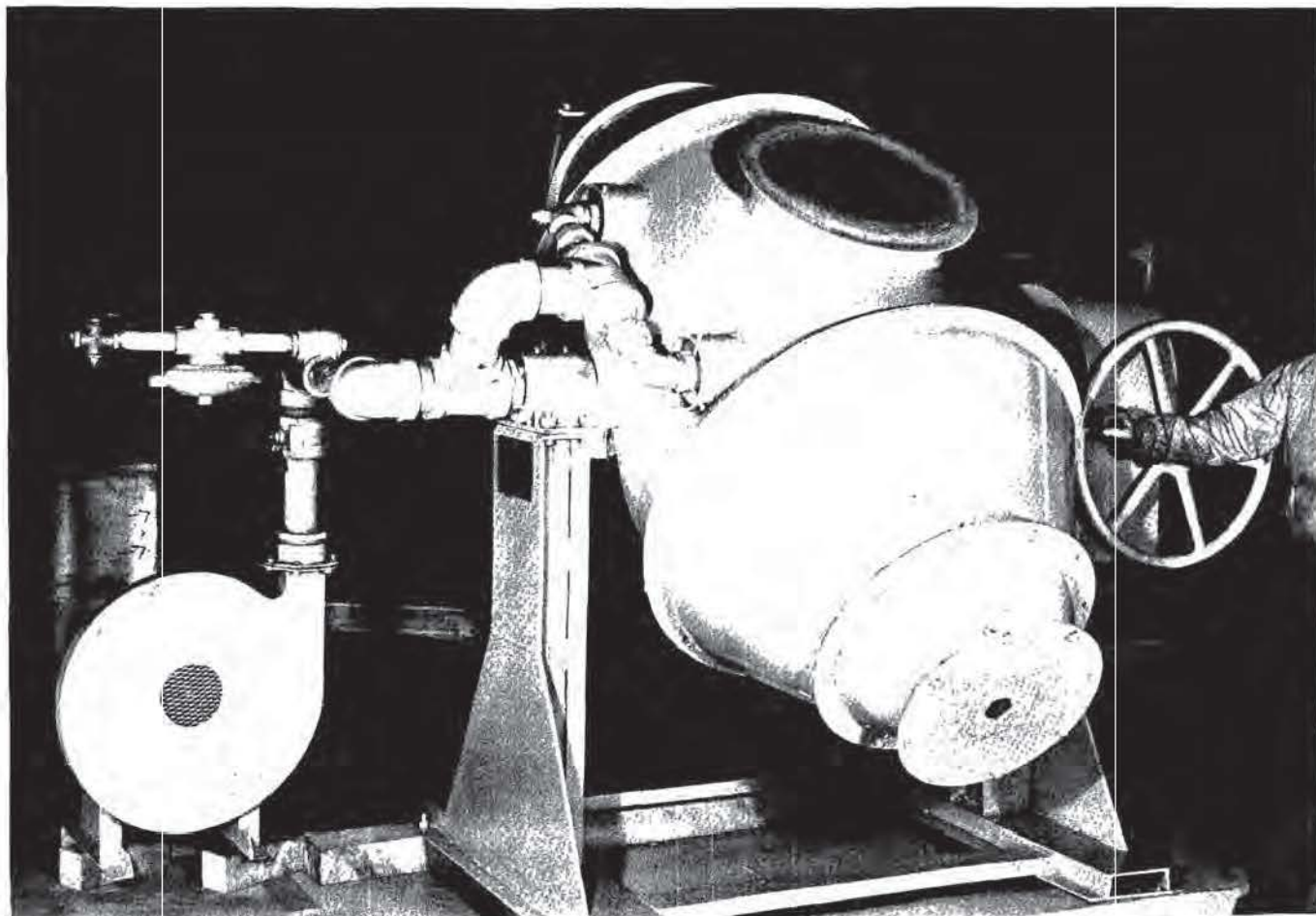operations--permanent mold, die casting, and sand operations. Charging is accomplished by means of a hopper that acts as a stack for the exhaust gases; the metal charge lodges in the lower part of the hopper where the melting takes place. The furnace is end fired, and tilting of the furnace is accomplished by means of an air or hydraulic ram.

Another type of tilting reverberatory furnace (Figure 161) normally finds application in nonferrous metallurgical operations where large heats are required. In this installation, the furnace is gas fired tangentially with three burners.

Many other variations and combinations of furnaces using the reverberatory principle are manufactured by many firms throughout the United States and are available commercially as prefabricated units.

CUPOLA FURNACE

For many years the cupola has been a standard melting furnace for producing gray iron. It is also used to melt or reduce copper, brasses, bronzes,

and lead. In addition to its high efficiency, the cupola is simple in its construction and operation. Unless carefully considered, however, its operation may lead to difficulties because of variations in quantity and quality of raw metal, fuel, and air.

The basic equipment for a gray iron-melting operation consists of the cupola (Figure 162), which is essentially a refractory-lined cylinder open at the top and equipped with air ports (known as tuyeres) at the bottom. Air is supplied from a forced-draft blower. Alternate charges of metal, coke, and limestone are placed on top of the burning coke bed to fill the cupola. The heat generated melts the metal, which is drawn off through a tap hole. The two principal dimensions of the cupola are its diameter and operating height (charging door to tuyeres). The diameter determines the melting capacity, and the height affects the thermal efficiency.

Combustion Air

The control of air at the tuyeres influences production rates, costs, metal losses, coke ratios, stack
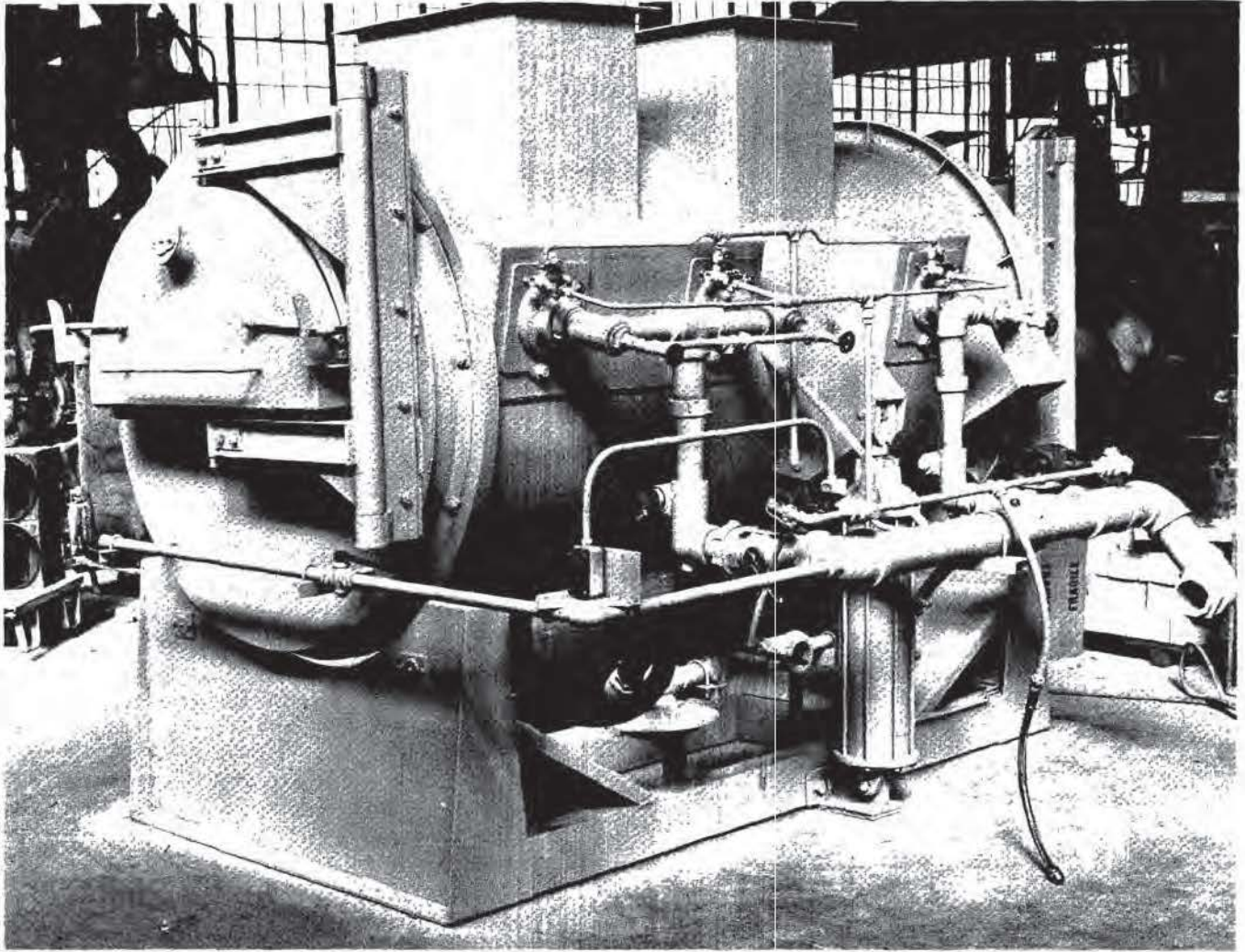
Figure 161. Tangentially fired tilting reverberatory furnace (Bulletin No. 6011, Hevi-Duty Heating Equipment Co., Watertown, Wisc.).

temperature, physical properties of the metal, and volume of stack emissions. Air is required, not only to furnish oxygen for the combustion of coke, which supplies the heat required for melting the iron, but also to aid in the potential combustion of the carbon, silicon, and manganese in the metal. The latter function greatly influences the resultant chemical and physical properties of the metal when it is poured into the mold (Molcohy, 1950).

Combustion air may be provided by a positive-displacement-type blower or a centrifugal blower. The quantity of air theoretically required is determined primarily by the size of the cupola, the melting rate, the metal-coke ratio, and the metal temperature. The actual air supplied may be increased as much as 15 percent to compensate for leakage. Air pressure varies from 8 to 40 ounces

per square inch, depending upon design factors such as ductwork layout, tuyere geometry, and the height of the bed through which the air must be forced. Automatic controls are frequently installed to maintain a constant-weight flow of air.

Methods of Charging

Various methods of charging materials into the cupola are used. The smaller cupolas are frequently charged by hand while larger units may be charged with skip hoists with the various types of cars, buckets, cranes, or trolleys. Charging and melting is a continuous operation.

Preheating Combustion Air

In order to increase the efficiency of a cupola, three methods are available for preheating combustion
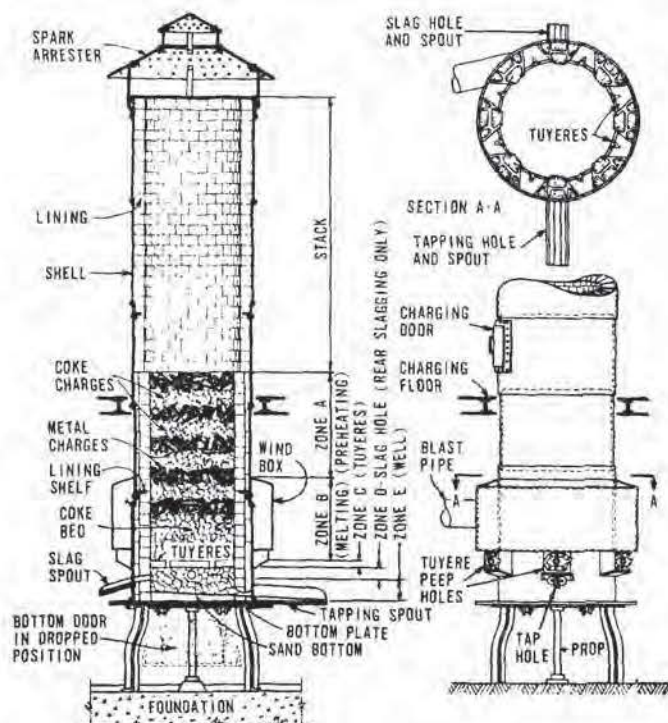
Figure 162. A cupola furnace (American Foundrymen's Association, 1949).

air. In the Moore system, a heat exchanger is used to transfer some of the waste heat of the stack gases to the incoming combustion air. The Whiting system uses a separate external heater for the combustion air. The Griffin system passes the stack gases through a chamber where air is introduced and the CO is burned to CO_2. The gases then pass through a heat exchanger to preheat the combustion air.

ELECTRIC FURNACE

Major advantages of the electric furnace over fuel-fired furnaces are furnace atmosphere control and high-temperature operation. Temperatures as high as 6,000°F are possible for special processes.

The electric furnace has three functions (Porter 1959):

1. Synthesis of compounds not available in the natural state by fusing selected raw materials,

2. purification of ores,

3. alteration of crystalline structure of ores having a satisfactory chemical purity but an undesirable crystal structure.

There are four types of electric furnace: Direct-arc, indirect-arc, resistance, and induction. Each of these types will be discussed briefly.

Direct-Arc Furnace

In the direct-arc furnace, many and varied arrangements are used to heat the metal charge, but radiation between arc and the metal bath is the principal method. Here, the heat is generated by radiation from the arc as well as from the resistance heat effect within the bath, as shown in Figure 163. Graphite and carbon electrodes are usually used and are spaced just below the surface of the slag cover. The current passes from one electrode through the slag, the metal charge, the slag, and back to the other electrode. In some arrangements, the current is carried from the metal charge to the hearth. The slag serves a protective function by shielding the metal charge from vaporized carbon and the extremely high temperatures at the arc.

Indirect-Arc Furnace

In the indirect-arc furnace, the metal charge is placed below the electrodes, and the arc is formed between the electrodes and above the charge (Figure 163). Indirect-arc furnaces are used mainly in the steel industry. One of the common smaller furnaces is the indirect-arc rocking furnace, in which an automatic rocking action of the furnace is employed to ensure a homogeneous melt. This is done by mounting the refractory-lined steel shell on cog bearings so that the furnace may be rocked through a 200° range. Radiated heat from the indirect arc, and conduction from the preheated refractory lining initially melt small scrap, forming a pool of molten metal at the bottom of the furnace. Then the rocking action is initiated, and the molten metal washes against the refractory, picking up additional heat, which is transferred by convection and radiation to the larger pieces of metal. During the heat, the rocking action is advanced gradually to avoid a sudden tumbling of cold metal, which could fracture the graphite electrodes.
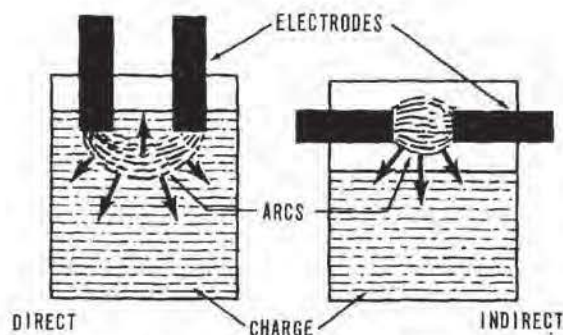

Figure 163. Principles of operation of two types of arc furnaces (Porter, 1959).

Induction Furnace

The induction furnace consists of a crucible within a water-cooled copper coil (Figure 164). An alternating current in the coil around the crucible induces eddy currents in the metal charge and thus develops heat within the mass of the charge. The furnace is used for the production of both ferrous and nonferrous metals and alloys, generally from scrap metal. It provides good furnace atmosphere control and can be used for large-volume production of high-purity materials.

Resistance Furnace

Three varieties of resistance furnaces are illustrated in Figure 165. The resistance furnace is essentially a refractory-lined chamber with electrodes, movable or fixed, buried in the charge. It is characterized by its simplicity of design and operation. The charge itself acts as an electrical resistance that generates heat.

The resistance furnace is used in the production of ferroalloys (ferrochrome, ferrosilicon, and others), cyanamide, silicon carbide, and graphite, and in hardening and tempering tools and machine parts.

CRUCIBLE FURNACE

Crucible furnaces, used to melt metals having melting points below 2,500°F are usually constructed with a shell of welded steel lined with refractory materials. Their covers are constructed of materials similar to the inner shell lining and have a small hole over the crucible for charging metal and exhausting the products of combustion. The crucible rests on a pedestal in the center of the furnace and is commonly constructed of a refractory material such as clay-graphite mixtures or silicon carbide. Crucibles are made in several shapes and sizes for melting from 20 to 2,000 pounds, rated in red brass.

Crucible furnaces are classified as tilting, pit, or stationary furnaces. All types are provided with one or more gas or oil burners mounted near the

Figure 164. Principles of operation of an induction furnace (Porter, 1959).
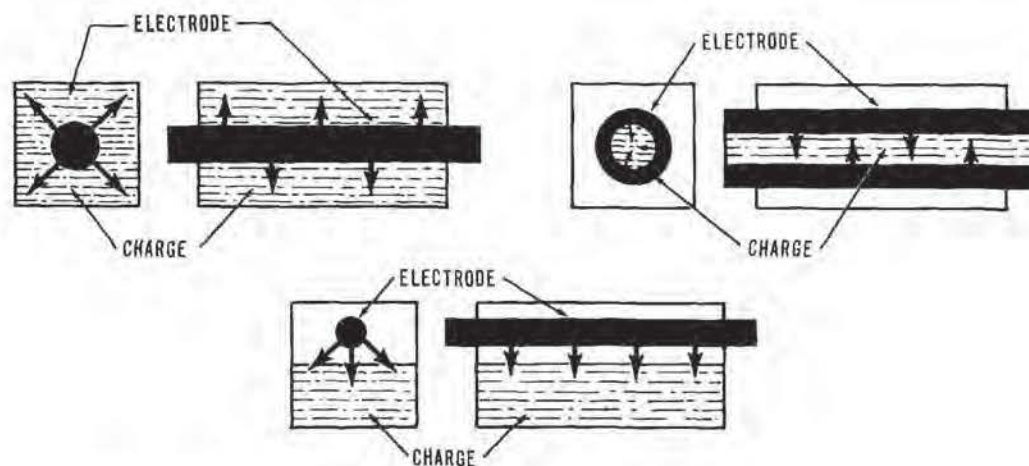

Figure 165. Principles of operation of three types of resistance furnace (Porter, 1959).

bottom of the unit. Flames are directed tangentially around the inside of the furnace. The crucible is heated both by radiation and by contact with the hot gases.

Tilting Furnace

The tilting crucible furnace (Figure 166) is provided with devices for affixing the crucible to the furnace so that the furnace may be tilted with the crucible when the metal is poured. The entire furnace is mounted on trunnions, around which the furnace may be tilted. The tilting mechanism can be operated manually, hydraulically, or electrically.
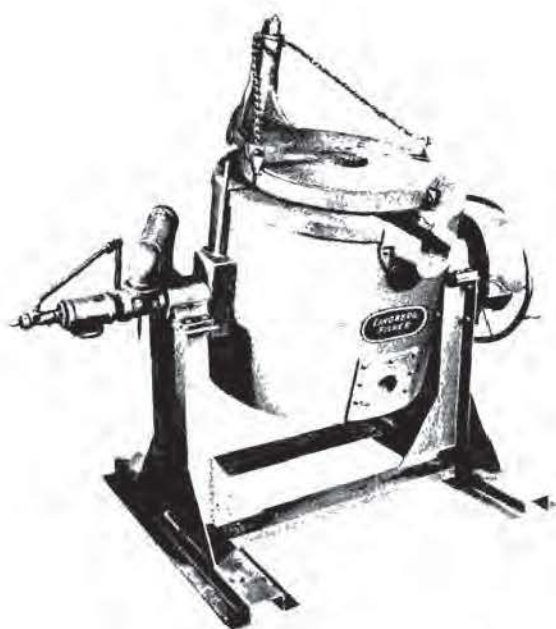
Figure 166. Tilting crucible furnace (Lindberg Engineering Co., Downey, Calif.).

Pit Crucible

The pit crucible furnace derives its name from its location. The top of the furnace is near floor level, which facilitates charging of the metal to the furnace and removing of the crucible for pouring. Pouring is usually accomplished by using the same crucible as a ladle. The furnace cover is provided with rollers or swinging mechanisms for easy removal.

Stationary Crucible

The stationary crucible furnace is almost identical to a pit furnace except that it is not sunk in a pit. These furnaces are commonly used as holding fur-

naces, and the metal is poured by dipping with hand ladles. Pouring may also be accomplished by removing the crucible and using it as a ladle.

POT FURNACE

Pot furnaces are used to melt metals with melting temperatures below 1,400°F. These furnaces may be cylindrical or rectangular and consist of an outer shell lined with refractory material, a combustion chamber, and a pot. The pots are made of pressed steel, cast steel, or cast iron with flanged tops. The flange rests on the furnace wall, holds the pot above the furnace floor, and seals the contents of the pot from the products of combustion of the fuel used. The shape of the pot depends upon the operation to be conducted. Large rectangular furnaces, generally called kettles, are used to melt large amounts of metal for dipping operations, such as galvanizing. For melting large castings, shallow, large-diameter pots are used. When ingots or other small pieces of metal are to be melted, deep pots are used to promote better heat transfer. Pot furnaces are usually emptied by tilting, dipping, or pumping. A small pot furnace is shown in Figure 167. Combustion equipment ranges from

Figure 167. A gas-fired small pot furnace (Lindberg Engineering Co., Downey, Calif.).

simple atmospheric-type burners located directly below the pot to premix-type burners tangentially fired as in crucible furnaces. The larger kettles are generally provided with many small burners along both sides of the pot.
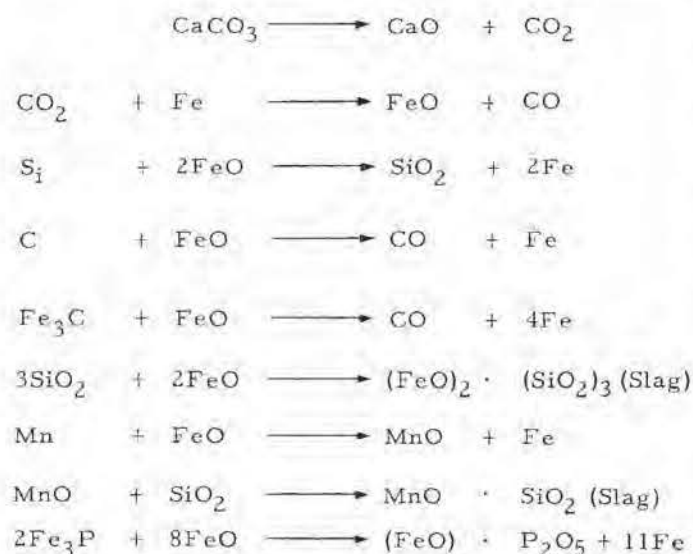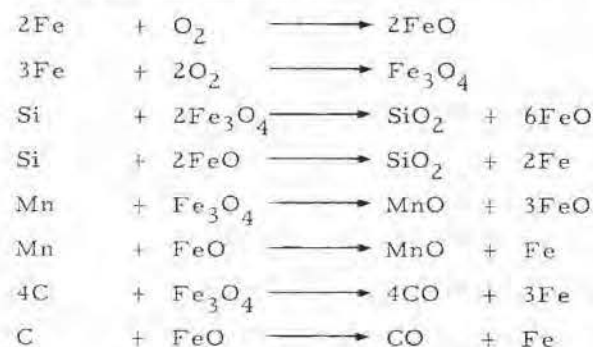
STEEL-MANUFACTURING PROCESSES

Steel is a crystalline alloy, mainly of iron and carbon, which attains greater hardness when quenched from above its critical temperature than when cooled slowly. Carbon is the most important constituent because of its effect on the strength of the steel and its ability to harden. Other constituents that may be present as impurities or as added alloying elements include manganese, silicon, phosphorus, sulfur, aluminum, nickel, chromium, cobalt, molybdenum, vanadium, and copper (Begeman, 1947).

Steel is made from pig iron and scrap steel by oxidizing the impurities, reducing the iron oxides to iron, and adding the desired alloying constituents. The two common steel-refining processes are: (1) The basic process, wherein oxidation takes place in combination with a strong base such as lime; and (2) the acid process, wherein oxidation takes place without the base addition. The two processes have the common purpose of removing the undesirable elements in the metal by the chemical reaction of oxidation reduction. Depending upon the alloy being produced, the elements removed from a melt may be silicon, sulfur, manganese, phosphorus, or carbon. These elements are not removed by direct chemical reaction but by indirect reaction. For a basic refining process, limestone is added as a flux, and iron ore or mill scale as an oxidizing agent. The reactions may be shown as follows (Clapp and Clark, 1944):
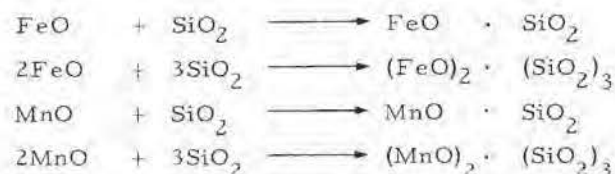
$$CaCO_3 \longrightarrow CaO + CO_2$$

$$CO_2 + Fe \longrightarrow FeO + CO$$

$$Si + 2FeO \longrightarrow SiO_2 + 2Fe$$

$$C + FeO \longrightarrow CO + Fe$$

$$Fe_3C + FeO \longrightarrow CO + 4Fe$$

$$3SiO_2 + 2FeO \longrightarrow (FeO)_2 \cdot (SiO_2)_3 \text{ (Slag)}$$

$$Mn + FeO \longrightarrow MnO + Fe$$

$$MnO + SiO_2 \longrightarrow MnO \cdot SiO_2 \text{ (Slag)}$$

$$2Fe_3P + 8FeO \longrightarrow (FeO) \cdot P_2O_5 + 11Fe$$

Sulfur is partially removed in the following manner, $CaO + FeS \rightarrow CaS + FeO$. The resulting CaS is taken up by the slag.

For an acid refining process the sequence of reactions can be shown in a similar manner as follows (Clapp and Clark, 1944):

$$2Fe + O_2 \longrightarrow 2FeO$$

$$3Fe + 2O_2 \longrightarrow Fe_3O_4$$

$$Si + 2Fe_3O_4 \longrightarrow SiO_2 + 6FeO$$

$$Si + 2FeO \longrightarrow SiO_2 + 2Fe$$

$$Mn + Fe_3O_4 \longrightarrow MnO + 3FeO$$

$$Mn + FeO \longrightarrow MnO + Fe$$

$$4C + Fe_3O_4 \longrightarrow 4CO + 3Fe$$

$$C + FeO \longrightarrow CO + Fe$$

The metallic oxides and silicon then form slags according to the equations:

$$FeO + SiO_2 \longrightarrow FeO \cdot SiO_2$$

$$2FeO + 3SiO_2 \longrightarrow (FeO)_2 \cdot (SiO_2)_3$$

$$MnO + SiO_2 \longrightarrow MnO \cdot SiO_2$$

$$2MnO + 3SiO_2 \longrightarrow (MnO)_2 \cdot (SiO_2)_3$$

Steel-refining processes are usually accomplished in the open hearth furnace, the electric furnace, or the Bessemer converter.

Open-hearth furnaces have an approximate range of 40 to 550 tons' capacity per heat with most falling in the 100- to 200-ton range. Because of the large capacities of these furnaces, they lend themselves to large-volume steel production.

The three types of electric furnaces used are the direct-arc, the indirect-arc, and the induction. Electric furnaces are most often used where only small quantities of pig iron are readily available and where remelting of steel scrap, or small heats of special alloys are required. Sometimes these furnaces are used with open-hearth furnaces. In such cases, the steel is first processed in an open-hearth furnace and is then further refined or alloyed in an electric furnace.

Still in limited use today is the Bessemer converter. It consists of a pear-shaped vessel or converter, mounted on trunnions and easily tilted for charging and pouring. Oxidation of manganese, silicon, and carbon is accomplished by blowing air through the molten metal. Converters have been largely replaced owing to the increased production rates achieved by the open-hearth and electric furnaces.

In 1960 over 4 million tons of steel (2.7 percent of the total production) was produced by a recently developed process called the oxygen process. This is similar to the Bessemer process in that an oxidizing gas, oxygen instead of air in this case, is blown through the molten metal. This oxygen-blowing process can be used as a rapid source of heat control to increase the temperature of the furnace bath or may be used to refine the metal by oxidizing the undesirable elements in the bath. The principal advantage of this process is that it shortens the refining time and thus reduces production costs.

In the oxygen process, pure oxygen is immediately available to promote oxidation of the impurities in the bath. If oxygen is used to reduce the carbon content, then carbon monoxide and iron oxide are formed, some oxygen remaining in the bath. Figure 168 shows this relationship for various bath carbon percentages. In the oxygen process, the oxygen also reacts at a slower rate with other elements such as silicon, manganese, and chromium to reduce the content of these elements in the molten bath.

Steel-making capacity in the United States by type of furnace is depicted in Table 64. In 1960 over 85 percent of the steel-making operating capacity

was represented by 906 open-hearth furnaces, 10 percent, by 301 electric furnaces, and 5 percent, by 31 Bessemer converters and 12 oxygen process furnaces. Total operating capacity was 148,571,000 tons.

Table 64. NUMBER AND CAPACITIES OF STEEL FURNACES OPERATED IN UNITED STATES, 1960 (Steel Facts, American Iron and Steel Institutes, New York, New York)

Furnace type	Number	Capacity, tons
Open hearth	906	126,621,630
Electric	301	14,395,940
Bessemer	31	3,396,000
Oxygen process	12	4,157,400

The air contaminants vented from steel-melting furnaces include gases, smoke, fumes, and dusts. The quantities of these contaminants in the effluent gas stream depend upon the types of material charged to the furnace. The gaseous emissions result from the combustion of fuels and other combustible contaminants in the furnace charge and from the refining process. Smoke emissions result from incomplete combustion of the combustibles in the furnace charge or of furnace fuels. Particulate emissions originate partially from dirt and impurities in the charge, but the major quantity results from the refining process.

A study of the chemical reactions of the refining processes reveals that a large portion of the particulate matter is emitted from steel furnaces in the form of metallic oxides. These characteristics are illustrated in Table 65, where the results of a spectrographic analysis of the particulate discharge from an open-hearth furnace are given, and in Table 66, which gives a typical analysis of the particulate discharge from an electric-arc furnace. These fume emissions or metallic oxides are very small, 65 to 70 percent falling into the 0- to 5-micron range. Table 67 shows a size analysis of the particulate emissions from an open-hearth furnace and two electric-arc furnaces along with other data. For a visual concept of particle size and shapes, electron photomicrographs of fumes from an electric-arc furnace and an open-hearth furnace are shown in Figures 169 and 170.

OPEN-HEARTH FURNACES

The open-hearth furnace, which features the regenerative principle, was invented by William Siemers in 1858. Although many improvements
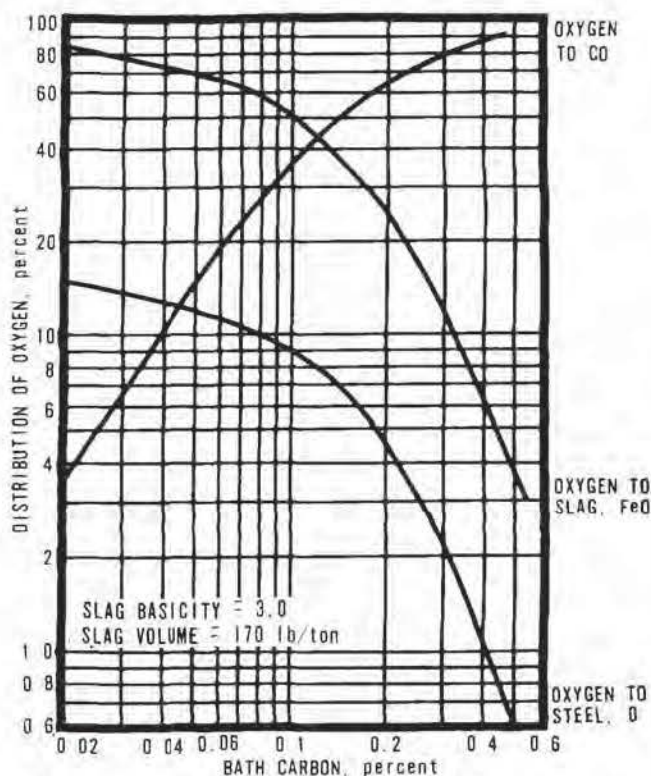

Figure 168. The oxygen reaction in molten steel (Obrzut, 1958).

Table 65. SPECTROGRAPHIC ANALYSIS OF
PARTICULATE DISCHARGE FROM AN OPEN
HEARTH FURNACE[a]

Element	Approximate amount, %
Fe	Remaining amount
Zn	10 to 15
Na	1 to 2
K	1 to 2
Al	5
Ca	5
Cr	2
Ni	2
Pb	5
Si	5
Sn	1
Cu	0.5
Mn	0.5
Mg	0.1
Li	Trace
Ba	Trace
Sr	Trace
Ag	0.05
Mo	Trace
Ti	Trace
V	0.05

[a]These data are qualitative only and require
supplementary quantitative analysis for actual
amounts.

Table 66. TYPICAL EMISSIONS FROM
AN ELECTRIC-ARC FURNACE
(Coulter, 1954)

Component	Weight %
Zinc oxide (ZnO)	37
Iron oxides	25
Lime (CaO)	6
Manganese oxide (MnO)	4
Alumina (Al_2O_3)	3
Sulfur trioxide (SO_3)	3
Silica (SiO_2)	2
Magnesium oxide (MgO)	2
Copper oxide (CuO)	0.2
Phosphorus pentoxide (P_2O_5)	0.2

and refinements have been made since then, the
process remains essentially the same. There are
roughly four methods of making basic open-hearth
steel in the United States. These are classed ac-
cording to the iron-bearing materials in the charge
as follows (Kirk and Othmer, 1947):

1. Hot metal (pig iron) and molten steel. By this
   method, iron from the blast furnace, and steel
   from the Bessemer converter are refined in
   the open-hearth furnace.

2. Cold steel scrap and cold pig iron. This com-
   bination is used by plants that have access to
   supplies of inexpensive scrap and do not have
   a blast furnace.

3. All steel scrap. This process is uncommon
   in the American steel industry.

4. Steel scrap and molten pig iron. Most of the
   integrated steel plants use this method, which
   is the predominant process in the United States
   and Canada.

In the last method, a typical initial charge consists
of 55 percent cold pig iron and 45 percent steel
scrap. Limestone and iron ore, equal in quanti-
ty to approximately 7 and 4 percent, respectively,
of the total weight of the cold metal charged, are
also added. If molten pig iron cannot be obtained
in sufficient quantity to complete the initial charge,
more cold pig is charged with the scrap, and the
entire mass is heated in the furnace. The process
continues for approximately 2 hours until the scrap
has reached a temperature of about 2,500°F and
has slightly fused. Molten pig is then added and
a lively action occurs in which almost all the sili-
con, manganese, and phosphorus, and part of the
carbon are oxidized. The first three elements
form compounds that slag with iron oxide and join
the iron and lime silicates that are already melted.
The ore acts on the carbon for 3 or 4 hours long-
er while the limestone forms carbon dioxide and
completes the purification. The lime boil lasts for
another 2 or 3 hours and the heat is then ready to
be adjusted for final carbon content by adding pig
iron, ore, or oxygen gas. The described operation
is commonly divided into three phases consisting
of the ore boil, the lime boil, and the working
period.

The heat for the process is provided by passing a
luminous flame with excess air over the charged
materials. The combustion air is alternately pre-
heated by two regenerating units, which, in turn,
are heated by the products of combustion discharg-
ing from the furnace.

The Air Pollution Problem

Air contaminants are emitted from an open-hearth
furnace throughout the process, or heat, which
lasts from 8 to 10 hours. These contaminants can
be categorized as combustion contaminants and
refining contaminants. Combustion contaminants
result from steel scrap, which contains grease,
oil, or other combustible material, and from the
furnace fuel.

The particulate emissions that occur in greatest
quantities are the fumes, or oxides, of the vari-
ous metal constituents in the steel alloy being made.
These fumes are formed in accordance with the

Table 67. DUST AND FUME DISCHARGE FROM STEEL FURNACES

Test number	1	2	3
Furnace data			
Type of furnace	Electric arc	Electric arc	Open hearth
Size of furnace	2 ton and 5 ton[a]	50 ton	50 ton
Process wt, lb/hr	3,755	28,823	13,300
Stack gas data			
Volume, scfm	7,541	23,920	14,150
Temperature, °F	125	209	1,270
Dust and fume data			
Type of control equipment	None	None	None
Concentration, gr/scf	0.1245	0.5373	1.13
Dust emissions, lb/hr	8.05	110.16	137
Particle size, wt %			
0 to 5 μ	67.9	71.9	64.7
5 to 10 μ	6.8	8.3	6.79
10 to 20 μ	9.8	6.0	11.9
20 to 44 μ	9.0	7.5	8.96
> 44 μ	6.5	6.3	7.65
Specific gravity	--	3.93	5

[a]Both furnaces are vented by a common exhaust system and were tested simultaneously.

refining chemistry previously discussed. The concentration of the particulates in the gas stream varies over a wide range during the heat, from 0.10 to a maximum of 2.0 grains per cubic foot (Allen et al., 1952). An average is 0.7 grain per cubic foot, or 16 pounds per ton of material charged. The test results in Table 67 for the open-hearth furnace show that 64.7 percent of the emissions are below 5 microns in size. The control device selected must, therefore, be capable of high collection efficiencies on small particles.

Another serious air pollution problem occurring with open-hearth furnace operation is that of fluoride emissions. These emissions have affected plants, which in turn, have caused chronic poisoning of animals. Surveys have shown that fluorides are contained in some iron ores such as those mined in southern Utah. Control of fluoride emissions presents a problem because these emissions are in both the gaseous and particulate state.

Hooding and Ventilation Requirements

The design parameters for an open-hearth furnace control system for duct sizes, gas velocities, and so forth are the same as those to be outlined for the electric-arc furnace. In order to establish the volume of gases to be vented from the furnace, the maximum fuel input must be known:

Example 25

Given:

60-ton open-hearth furnace. Fuel input = 35 lb of U.S. Grade No. 6 fuel oil per min.

Problem:

Determine the volume of gases to be vented from the furnace stack to the air pollution control system.

Solution:

1. Volume of products of combustion from oil burners:

One pound of U.S. Grade No. 6 fuel oil with theoretical air produces 186.1 scf gas (see Table D6 in Appendix D).

$$V_{PC} = 35 \times 186.1 = 6,510 \text{ scfm}$$
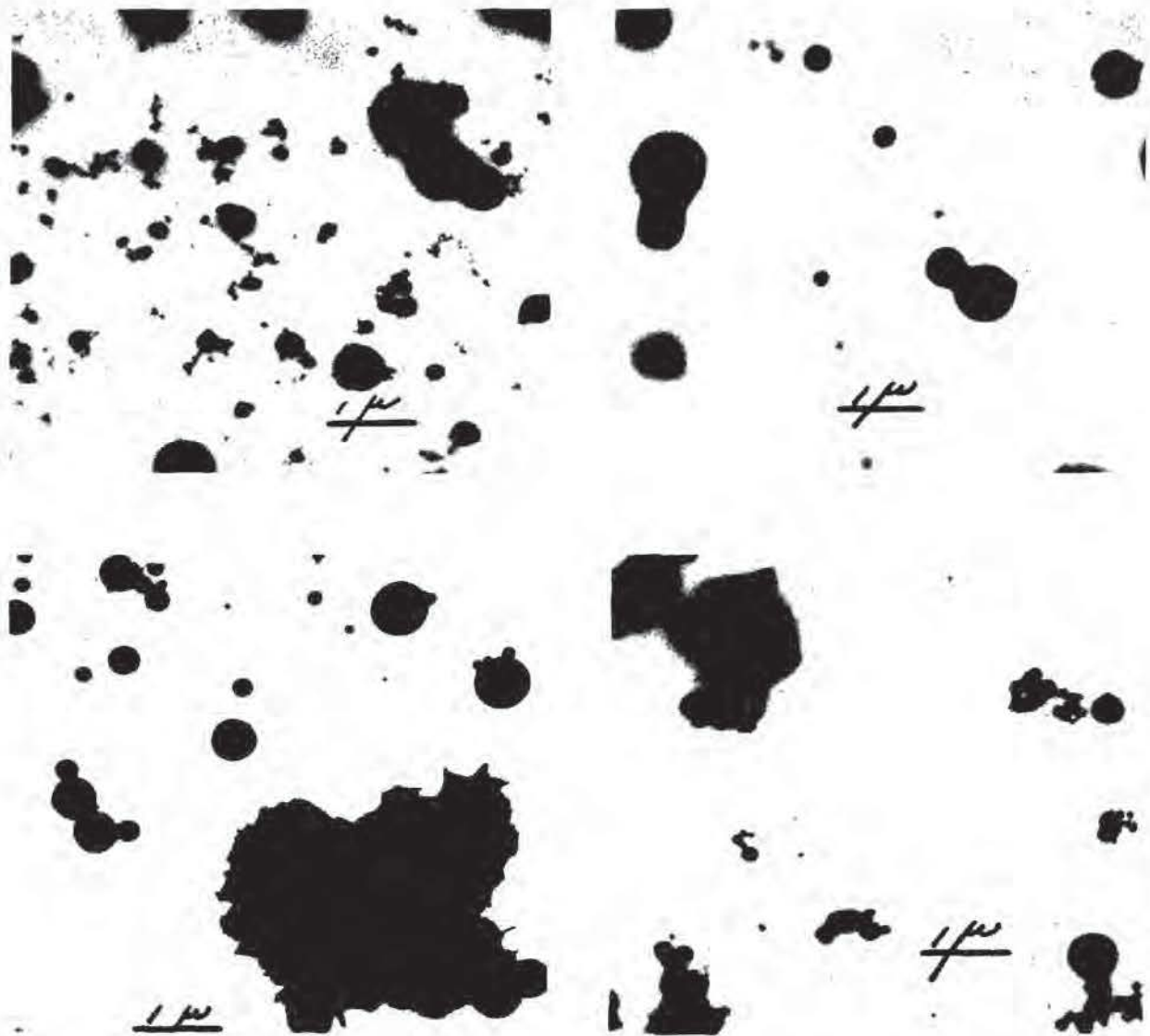
Figure 169. Electron photomicrographs of fumes from an electric furnace producing steel
for castings (Allen et al., 1952).

2. Volume of air infiltrated through leaks owing
to reversing valves, stack dampers, cracks
in bricks, and so forth:

Assume the average 150 percent excess air
(combustion and infiltration) usually found in
the stacks of regenerative furnaces. Theo-
retical air for 1 pound of U.S. Grade No. 6
fuel oil is 177.2 scf (see Table D6 in Appen-
dix D).

$$V_{EA} = 35 \times 177.2 \times 1.5 = 9,320 \text{ scfm}$$

3. Total volume at 60°F to air pollution control
equipment:

$$V_{T60} = V_{PC} + V_{EA}$$
$$= 6,510 + 9,320 = 15,830 \text{ scfm}$$

The temperature of the furnace gases leaving
the regenerator will be approximately 1,300°F.
In some installations, this heat source is used
to generate steam by delivering the gases to
a waste heat boiler in which the temperature
would be reduced to about 500°F.
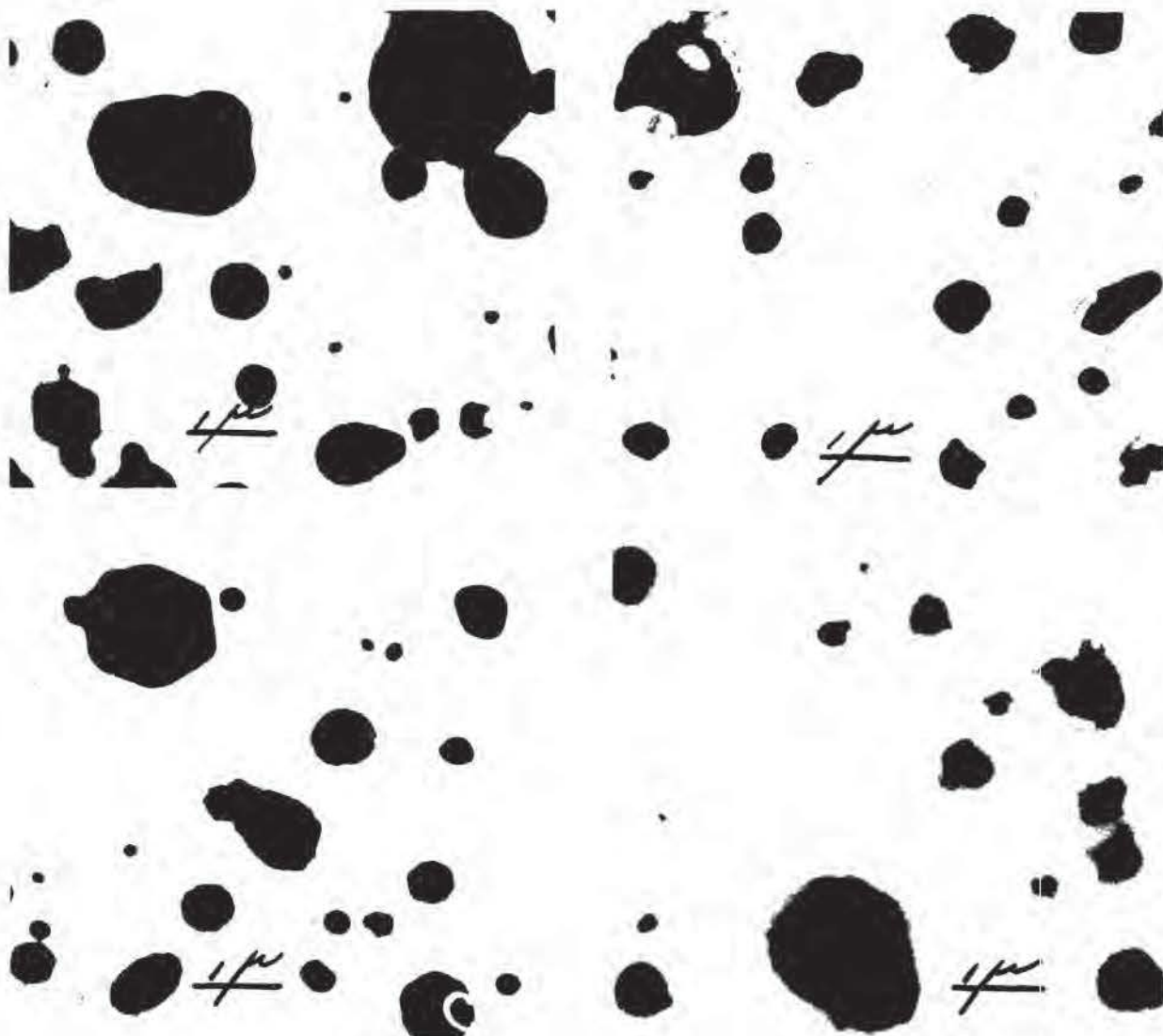
Figure 170. Electron photomicrographs of fumes from a cold-metal open-hearth steel furnace (Allen et al., 1952).

4. Total volume of the air pollution control equipment at 500°F operating temperature:

$$V_{T500} = 15,830 \times \frac{460 + 500}{460 + 60} = 29,200 \text{ cfm}$$

Since the efficient operation of the open-hearth furnace requires that all the products of combustion, along with the air contaminants created in the furnace, are to be conducted through the regenerator and then to a stack, it is necessary only to direct the flow from the stack through suitable ductwork to the control system. The size of the blower must, of course, be increased to overcome the additional resistance introduced by the control system.

Air Pollution Control Equipment

Open-hearth furnaces have been successfully controlled by electrical precipitators. On some installations, the control system has been refined by installing a waste heat boiler between furnace and control device. In this manner, heat is reclaimed from the furnace exhaust gases, and at the same time, the gases are reduced in temperature to within the design limits of the control device. In Table 68 are shown test results of a control system wherein the waste heat boiler and electrical precipitator vent an open-hearth furnace. This test was made on one of four control systems installed to serve open-hearth furnaces. These control systems are shown in Figure 171.

Table 68. DUST AND FUME EMISSIONS FROM
AN OPEN-HEARTH FURNACE SERVED BY AN
ELECTRICAL PRECIPITATOR

Furnace data:	
Type of furnace (constructed 1916)	Open hearth
Size of furnace, tons	63
Test interval	1 hr during heat working period
Fuel input	Natural gas, 21,000 cfh
	Fuel oil, 1.4 gpm
Waste heat boiler data:	
Gas volume, inlet, scfm	14,900
Gas temperature, inlet, °F	1,330
Gas temperature, outlet, °F	460
Water in waste gas, %	12.4
Steam production (average), lb/hr	8,400
Precipitation data:	
Gas volume, scfm	14,900
Dust and fume concentration (dry volume)	
Inlet, gr/scf	0.355
Outlet, gr/scf	0.004
Inlet, lb/hr	39.6
Outlet, lb/hr	0.406
Collection efficiency, %	98.98

The factors to be considered in designing an electrical precipitator to control the emissions from an open-hearth furnace are the same as those that will be described next.

Electric-Arc Furnaces

The electric-arc furnace lends itself to accurate control of temperature and time of reaction for producing desired alloy composition. These advantages are achieved because no harmful gases are emitted from an electric arc that would otherwise produce an adverse effect upon the metal being refined. Steel may be produced in an arc furnace by either the basic or the acid process. The furnace may be charged with molten metal from an open-hearth furnace (an operation known as duplexing), or it may be charged with cold steel scrap. Owing to the close control that can be achieved, low-grade scrap can be refined to meet close specifications of the various steel alloys.

After the furnace has been charged with metal, fluxes and other additions required to accomplish the refining chemistry are charged according to schedule. The additions vary depending upon the composition of steel desired and the metal charged. Lime is usually a basic addition along with others, such as sand, fluorspar, iron ore, carbon, pig iron, and other alloying elements. The operation then continues in three phases: (1) The oxidizing period, in which the undesirable elements are oxidized from the metal and removed as slag, (2) the reducing period, in which oxygen is removed from the metal mostly through the reaction with carbon, and (3) the finishing period, in which additions are made to bring the alloy within the desired specifications. The make-up of a typical charge to an electric-arc furnace is shown in Table 69.

Table 69. TYPICAL CHARGE FOR AN
ELECTRIC-ARC FURNACE (Coulter, 1954)

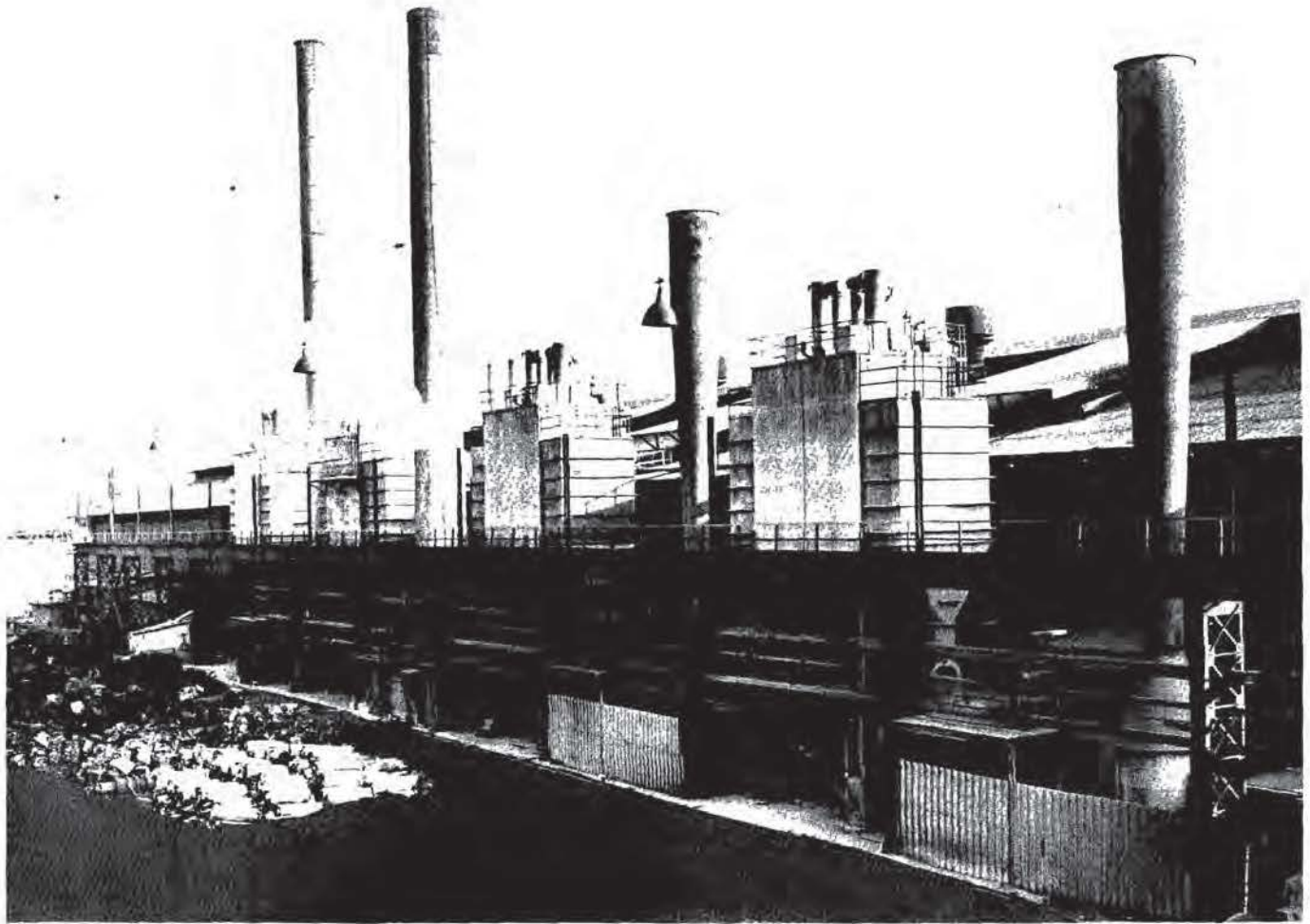| Material	Weight %
Fluxes, carbon, and ore	5
Turnings and borings	7
Home scrap	20
No. 2 baled scrap	25
Miscellaneous scrap (auto, etc)	43

Figure 171. Electrical precipitators serving open-hearth furnaces.

The Air Pollution Problem

The quantity and type of fumes emitted from an electric-arc furnace depend upon several factors: Furnace size, type of scrap, composition of scrap, cleanliness of scrap, type of furnace process, order of charging materials, melting rate, refining procedure, and tapping temperature. A large portion of the fumes generated in a furnace is retained in the slag; however, sizable quantities of fumes escape and are discharged from the furnace vent. Table 70 shows emission data, which vary from 4.5 to 29.4 pounds of fumes per ton of metal melted. Most of the emissions originate during the first half of the heat. Figure 172 shows a curve of emission rates during a single heat.

Hooding and Ventilation Requirements

Before the emissions can be collected they must first be captured through some suitable hooding arrangement at the furnace and must then be conveyed to a collection device that has a high collection efficiency on small particles.

Four types of hooding arrangements can be installed. The first is a canopy-type hood, which is suspended directly over the furnace (Figure 173). A hood such as this has serious deficiencies in that it must be mounted high enough above the furnace to clear the electrodes and not interfere with the crane when overhead charging is employed. As the distance between the furnace and hood is increased, the volume of air to be inspirated into

Table 70. ELECTRIC-ARC STEEL FURNACE
EMISSION DATA (Brief et al., 1956)

| Case	Rated furnace size, tons	Average melting rate, tons/hr	Cycle time, hr	Fume emission/ton melted, lb/ton	Furnace process
A	50	18.3	4	9.3[c]	
	75	23.5	4	18.6[d]	Basic, single slag
	75	23.5	4	--	
B	50[a]	14.4	4	7.6	
	50[a]	13.6	4	6.9	Basic, single slag
	75[a]	21.9	4	12.3	
	3	1.5	2	12.6	Acid, oxygen blow
	3	1.1	2	7.6	Acid, oxygen blow
	6	3.1		10.4	
	10	6.6	2	5.5	Basic, oxygen blow
	10	5.4	2	5.2	Basic, oxygen blow
	2[b]	1.5[b]		13.4	
C	3	1.9	2	4.5	Acid
	3	1.6	2	5.8	Acid
	3	1.9	2	5.7	Acid
	6	2.6	2.33	15.3	
	6	3.0	2	12.8	
D	18	5.4	3	6.1	
E	6	4.1	1.2	29.4	Acid, single slag
F	3	1.8	1.75	12.7	Acid, single slag

[a]Refer to same furnace as case A.
[b]Two 2-ton furnaces operating in parallel.
[c]Average for one 50-ton and two 75-ton furnaces processing normal scrap.
[d]Average for one 50-ton and two 75-ton furnaces processing dirty, sub-quality scrap.
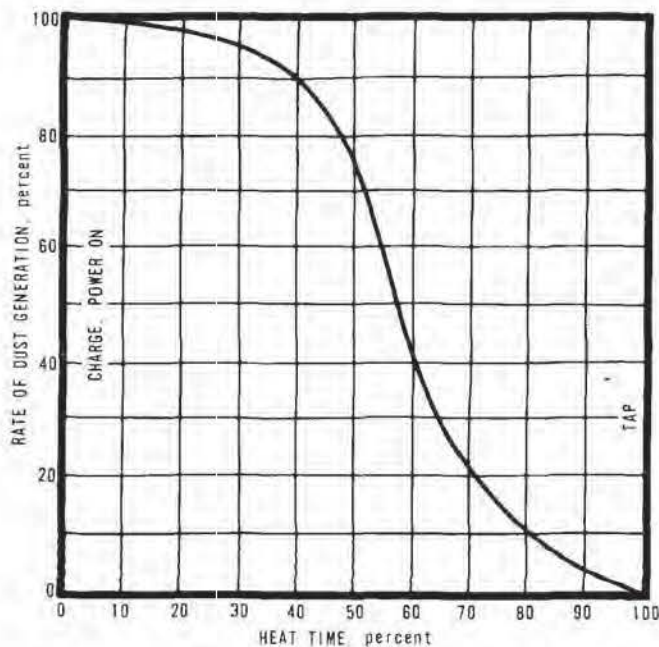
Figure 172. Curve showing rate of fume emission during a heat of an electric-arc furnace (Coulter 1954).

the hood also must be increased to achieve satisfactory capture of the furnace emissions.

The second hood type (Figure 174) is called a plenum roof. Here a flat hood is attached to the furnace roof ring and has pickup openings over the charging door, the pouring spout, and the electrode openings. Holes in the top of the hood admit the electrodes. This type of hood must have a telescoping or swivel connection, or both, to the exhaust system to permit tilting and pouring operations of the furnace. For top-charge furnaces, the hood must be sectioned and installed with an exhaust system disconnect joint to permit roof removal. Because of this feature, these furnaces are necessarily uncontrolled during the charging operation. This type of hood is shown in Figure 175. The 25-ton furnace with plenum hood is one of three furnaces venting to the baghouse.

In the third type of hood, the furnace roof is tapped and vented directly to the exhaust system, which permits the furnace to serve as its own hood. With
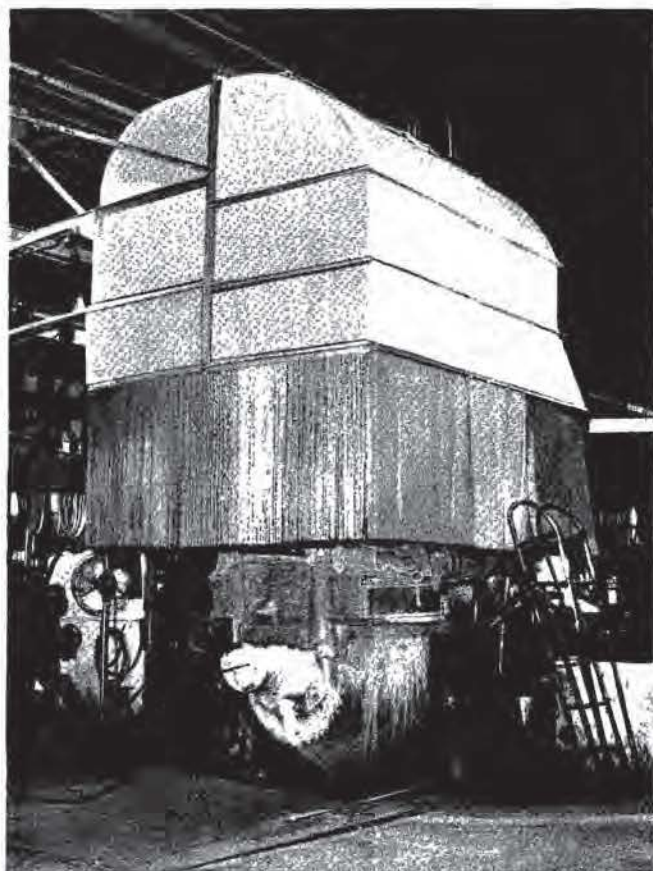
Figure 173. Electric-arc furnace venting to a canopy-type hood.

mit movement of the electrode holder. Smaller ducts extend from the main duct to the slagging door and tapping spout. The main duct joint is provided with a swivel and/or telescoping section to permit some control during tapping. No provision is made for collection of emissions that may leak between the roof and the furnace, except for the use of a soft sand seal.

This system provides high-velocity indraft air around the electrodes (1,000 to 2,000 fpm) to capture the emissions released around the electrodes. The hood over the slagging door captures emissions generated from this point, and the hood over the tapping spout provides partial capture.

A hood should be designed so that a positive indraft of air through all hood openings will prevent escape of fumes. The design air volume to ventilate an electric-arc furnace with an integral hood is approximately 2,500 cfm per ton of charge. If a canopy-type hood is used, a velocity of 200 fpm should be maintained between the furnace and the hood (Committee on Industrial Ventilation, 1960). Design figures such as these must, however, be used with discretion, depending upon the individual furnace to be controlled. Table 71 contains design data for several actual installations.

this arrangement, air is inspirated through all furnace openings and vented directly to the exhaust system. Here again, the furnace becomes uncontrolled when the roof is removed during charging. It is also uncontrolled when tilted during the pouring operation unless a telescoping and swivel duct connection is installed. Since this type of hooding results in high effluent gas temperatures from the furnace, flame and cinder traps should be installed on the larger furnaces, and some provision for cooling the gas stream may have to be made. This is particularly true if the charged scrap contains combustible contaminants. Depending upon the materials and type of construction, the duct connections to the furnace may have to be water jacketed for cooling. Figure 176 illustrates a roof tap with a stainless steel duct connection.

A fourth general type of hood is known as a side-draft hood. This hood consists of a large duct that extends from the side of the furnace to the area where the electrodes enter the furnace through the roof. Here, the duct divides into three sections with each section flaring to wrap approximately 180 degrees around each electrode. The flared ends are positioned as closely as possible to the electrodes yet sufficient room is retained to per-

The duct system must be designed to maintain a satisfactory conveying velocity for the furnace emissions. These fine metallic fumes can be satisfactorily conveyed at a velocity of 3,500 fpm. Another design feature that must be considered is that of cooling the effluent gas stream to within operating temperature limits for cloth filters. With a canopy-type hood, large quantities of dilution air are taken in through the hood, which effectively reduce the effluent gas temperature. With the plenum roof, direct furnace tap, and side-draft hoods, however, there are intervals when the effluent gas stream temperatures are excessive, and some type of cooling is required.

Cooling may be accomplished by radiation-convection cooling columns, by water-spray nozzles, or by dilution air. In installations where cooling is required only during a short portion of the operating cycle, a dilution air damper can be installed in the exhaust system that automatically opens to prevent the gas stream's temperature from exceeding the limits of the filter cloth. The effects of these cooling methods upon duct, fan, and motor selection must be considered in designing the exhaust system. The introduction of water into an exhaust system invites accelerated corrosion.
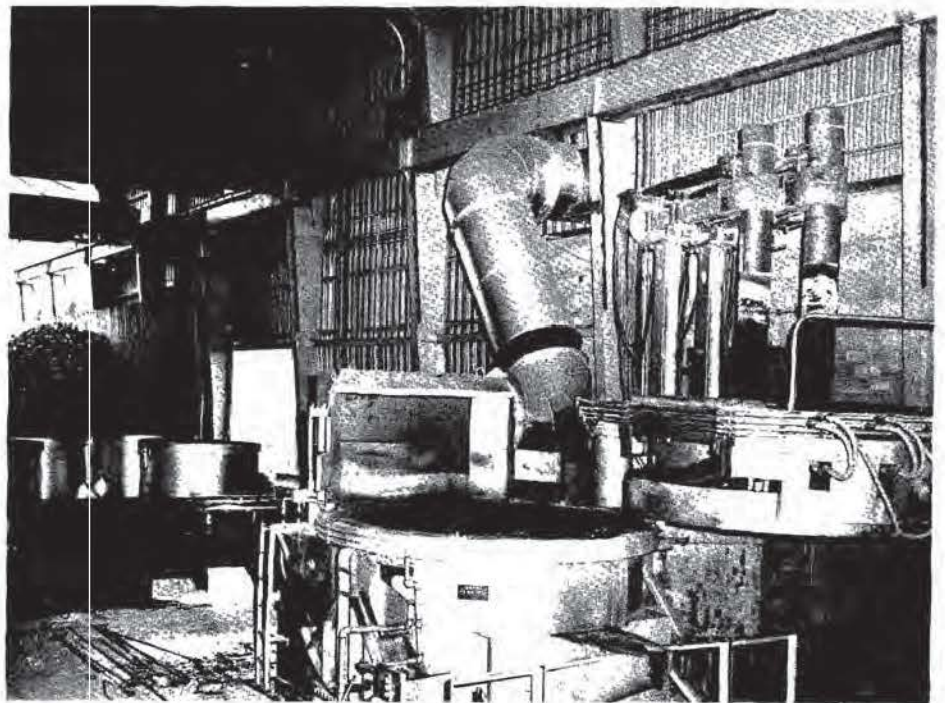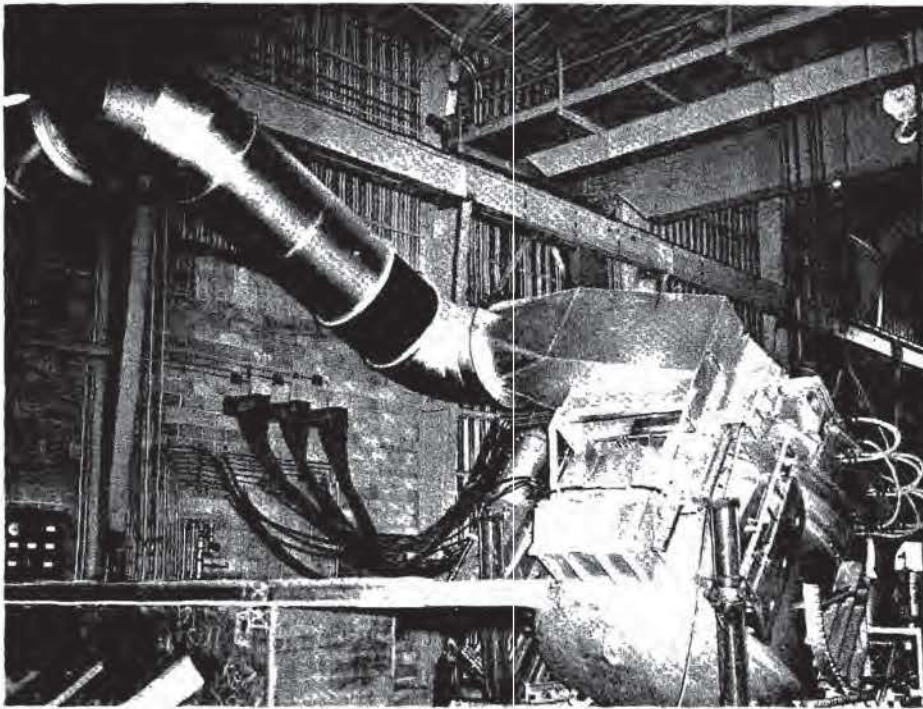
Figure 174. Close-fitting plenum-type hood serving an electric-arc furnace:
(left) furnace filled with hood in place. (right) furnace with hood removed
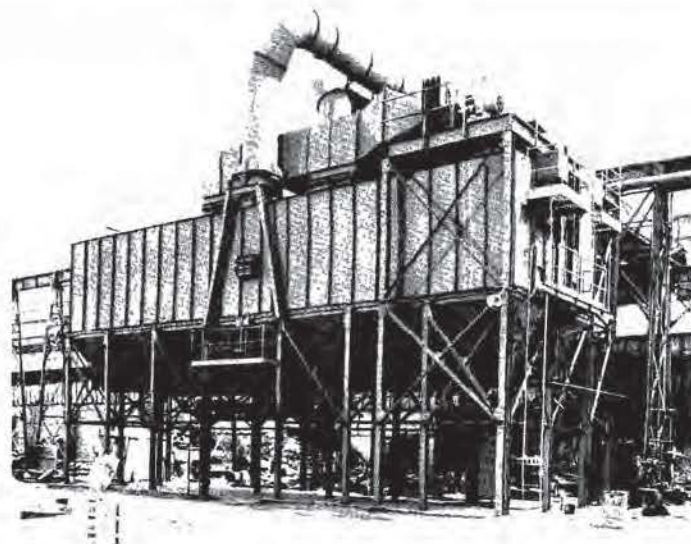(Soule Steel Company, Los Angeles, Calif.).

Figure 175. (Left) electric-arc furnace with plenum hood, (right) venting to a baghouse (National Supply, Torrance, Calif.).
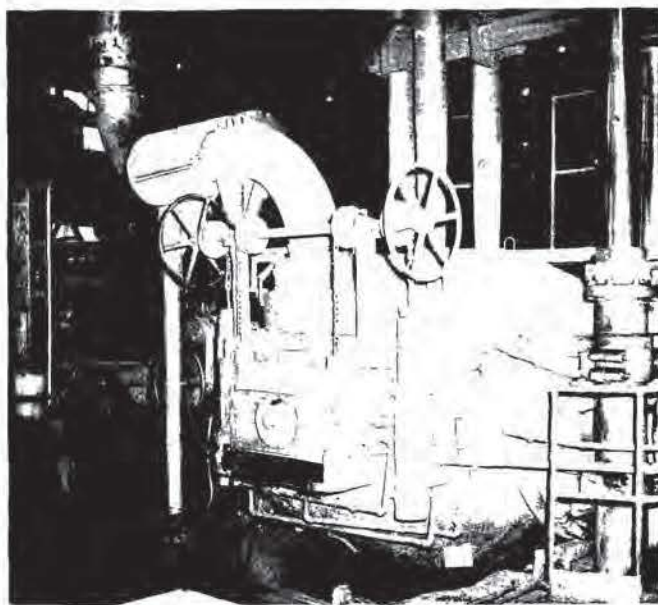

Figure 176. Direct roof tap on an electric-arc furnace (Alloy Steel and Metals Company, Los Angeles, Calif.).

Sometimes, local opacity regulations cannot be met through the use of only a close-fitting hood. This type of control leaves the furnace uncontrolled during charging and only partially controlled during tapping. While the initial charge may not produce large quantities of emissions, any later backcharge usually produces objectionable smoke and fumes. The tapping of the furnace also produces fumes that escape collection.

When additional equipment is needed to control emissions created during charging and tapping, it

is advantageous to select a design adaptable to existing plant facilities and compatible with furnace operations. A high canopy hood can meet these needs if it is located directly over the furnace between the roof and the crane line. All roof monitors or exhaust fans nearby must be closed and sealed. The building must be enclosed to prevent free movement of wind through the plant. Cross-drafts must be kept to a minimum near the furnace to prevent the emissions from being blown away from the hood. Free-standing side panels, adjacent to the furnace and extending from near floor level to crane height, may be required. The size of the hood and air volume required to be exhausted are determined by using the formulas developed in Chapter 3. During charging or tapping operations, the close-fitting-hood control system is not used and is dampered, and the canopy hood captures the emissions. This procedure eliminates the need for exhausting air from both hoods at the same time, and thereby reduces the size of the control system. The canopy hood should have sufficient internal volume to prevent spillage of fumes during the violent burst of emissions created by the backcharges.

When more than one furnace is to be controlled, the size of the control system can be minimized by arranging the furnace melting cycles to allow only one furnace tapping and charging cycle or one furnace melting cycle to occur at any one time. The control system also can be used to vent the station where the "skulls," or unpoured metal, are burned out of the ladle.

Table 71. ELECTRIC STEEL FURNACE AND BAGHOUSE COLLECTOR DATA

	A	B	C	D	E	F	G	H
Total number of furnaces	3	1	1	1	4	3	2	2
Furnace nominal size, tons	25, 6, 2	15	12	16	3/4, 3, 3, 3	2, 2, 1/2	3 2	3 3
Furnace actual charge, tons	25, 8, 2	17	14	19	3/4, 4-1/2, 4-1/2, 4-1/2	4, 4, 3/4	3-1/2, 2-1/2	3-1/3, 3-1/3
Furnace energy rating, kv-a	5,000, 5,000, 1,500	6,000	6,000	7,500	750, 1,400 1,800, 1,800	1,500, 1,500, 800	1,500, 1,000	1,750, 1,750
Average heat time, hr	6-1/2, 3-1/2, 3	2	2-1/2	2-1/2	2, 2, 2, 2	2, 2, 2	1-1/2, 2	2, 2
Oxygen blow	Yes	Yes	No	No	Yes	No	Yes	Yes
Design volume of blower, cfm	60,000	47,000	60,000	60,000	32,000	26,200	13,800	8,000
Gas volume/ton charged, cfm/ton	2,140[a]	2,610	4,280	3,160	2,370[b]	2,760	3,940[c]	1,200
Type of baghouse	Compartmented tubular	Sectioned tubular	Compartmented tubular	Sectioned tubular	Sectioned cloth screen	Compartmented tubular	Compartmented tubular	Reverse air jet
Filter material	Dacron	Orlon	Orlon	Orlon	Cotton	Orlon	Orlon	Orlon
Filter area, ft^2	30,720	20,800	25,760	26,304	11,220	11,760	5,540	884
Filtering velocity, fpm	1.96	2.26	2.33	2.28	2.85	2.23	2.5	9.06
Shaking cycle, min	60	120	60	150	60	60	60	Continuous
Precleaner	None	None	Cinder trap	Cinder trap	WD roto-clones	None	None	Rotoclone
Hood type	Roof enclosure	Roof enclosure	Roof enclosure	Roof enclosure	Canopy	Roof enclosure	Roof enclosure	Direct furnace tap
Hood duct connection	Telescoping-articulating	Telescoping-articulating	Telescoping-articulating	Telescoping-articulating	Permanent	Slip flange	Slip flange	Special slip flange[d]
Cooling method	15,000 cfm blower	Long duct	Long duct and cinder trap	Long duct and cinder trap	Water	Long duct	Long duct	Water

[a] With all blowers and furnaces in use.
[b] A 3/4-ton furnace not included--standby.
[c] Only one furnace operated at a time--2-1/2 ton standby.
[d] Provides continuous connection to duct during slag and tap.

Air Pollution Control Equipment

Baghouse dust collectors

The baghouse control device must be designed with features that make its operation compatible with the operation of the furnace and exhaust system. The baghouse must have a filter area that efficiently removes the particulate matter from the gas stream. The filtering velocity should not exceed 2.5 fpm. Since high temperatures are reached periodically, Dacron or glass fiber are used for this service. Dacron can withstand temperatures up to 275°F, and glass fiber can withstand temperatures up to 500°F. Electric furnace fumes tend to agglomerate, and the bags must be shaken sufficiently to remove the collected fumes from the cloth surface. The temperature of the effluent gas stream entering the baghouse must not be allowed to fall below the dewpoint, or blinding of the bags results. This, in turn, reduces the exhaust air volume, causing poor pickup of fumes at the source. Blinding of the bags also makes bag cleaning more difficult. The baghouse should be compartmented so that one section at a time can be isolated and bags shaken to allow continuous system operation. It should be equipped with hoppers that facilitate the removal of the collected material. Screw conveyors are frequently installed on the hoppers as an aid for removing the material collected.

Control unit assembly must be constructed of materials that can withstand the temperatures of the furnace and the effluent gas stream. Provision should also be made to prevent sparks and burning material from entering the collector.

An outline of some of the design features of baghouses that serve electric steel-melting furnaces is included in Table 71. Only one of these installations was equipped for reverse air cleaning. This particular baghouse has been replaced with a conventional shake cleaning unit because of the high maintenance costs associated with the reverse air cleaning mechanism and because of the excessive bag wear.

In Table 72 are shown test results of air pollution control systems with baghouses serving electric-arc steel-melting furnaces. The collection efficiencies of the baghouses in tests 1, 2, and 3 are within the range of expected efficiencies for installations of this type. In tests 4 and 5 the collection efficiencies are subnormal, indicating malfunction of the systems. This was evident at the time of the tests from the visible discharge of dust and fumes from the baghouse outlets. An investigation disclosed that those two baghouses had many defective bags. The results, however, are reported to emphasize the necessity of checking the validity of tests such as these.

Electrical precipitators

An electrical precipitator may be used to control the emissions from an electric-arc furnace. The fundamental design considerations for hooding, air volume cooling, duct sizing, and fan selection are the same as those outlined for baghouse control. The one major difference pertains to the conditioning of the effluent gas stream. A baghouse system should be designed so that the gas temperature remains below the maximum operating temperature of the cloth bags and above the dewpoint. For an electrical precipitator, control must be much more accurate. The apparent resistivity of the material to be collected must first be determined. After this is known, the condition of the gas stream, and the temperature and humidity that will result in the most efficient collection can be determined. Efficient collection usually falls within a narrow temperature range, in which case the conditioning system must be designed to maintain the effluent gas stream within that range. Figure 177 shows the relationship between temperature, humidity, and collection efficiency for an electrical precipitator serving an electric-arc furnace in a specific installation. For this particular installation an acceptable efficiency was not realized until the gas temperature was maintained below 127°F and the humidity above 49 percent. Table 73 shows operating data for two installations of electrical precipitators serving electric-arc furnaces.

One general equation (Brief et al., 1956) for expressing precipitator efficiency is

$$E = 1 - K^{\frac{L}{V}} \qquad (100)$$

where

E = collection efficiency

K = precipitation constant (always less than unity and dependent upon the resistivity of the fume for a specific degree of gas conditioning)

L = electrode length, ft

V = volumetric flow rate, cfm.

This equation shows some of the factors that must be considered before the control system can be designed. Factors such as efficiency required, resistivity of fume, gas conditioning, geometry of

Table 72. DUST AND FUME EMISSIONS FROM ELECTRIC-ARC
STEEL FURNACES WITH BAGHOUSE CONTROLS

Test number	1	2	3	4	5
Furnace data					
Type of furnace	3-electrode Direct arc	3-electrode Direct arc	Two, 3-electrode Direct arc	3-electrode Direct arc	3-electrode Direct arc
Size of furnace, tons	17	3-1/2	4/4	14	19
Process wt, lb/hr	13,700	4,250	3,380/5,131	17,650	22,300
Baghouse data					
Type of baghouse	Sectioned tubular	Compartmented tubular	Sectioned tubular	Compartmented tubular	Sectioned tubular
Filter material	Orlon	Orlon	Orlon	Orlon	Orlon
Filter area, ft^2	20,800	5,540	11,760	25,760	26,304
Filtering velocity, fpm	1.95	1.78	1.20	1.23	1.75
Dust and fume data					
Gas flow rate, scfm					
Inlet	38,400	10,300	12,960	18,700	42,300
Outlet	40,600	9,900	14,110	31,700	46,100
Gas temperature, °F					
Inlet average	172	135	129	186	167
Outlet average	137	106	121	139	153
Concentration, gr/scf					
Inlet	0.507	0.346	0.398	0.370	0.462
Outlet	0.003	0.0067	0.0065	0.0158	0.047
Dust and fume emission, lb/hr					
Inlet	166.9	30.5	44.2	59.3	167.5
Outlet	1.04	0.57	0.79	4.3	18.5
Control efficiency,%	99.4	98.1	98.2	92.7[a]	88.9[a]
Particle size, wt %					
Inlet, 0 to 5 μ	72.0	57.2	63.3	59.0	43.3
5 to 10	10.5	37.8	17.7	33.1	17.7
10 to 20	2.7	3.4	8.0	4.9	6.4
20 to 40	4.7	1.6	8.1	3.0	14.60
> 40	10.1	0	2.9	0.0	18.0
Outlet	100% < 2 μ	100% < 1 μ	100% < 2 μ	72% < 5 μ	75% < 5 μ

[a]An investigation disclosed that poor efficiencies were due to defective bags in the baghouse.

precipitator, and others should all be discussed with a manufacturer of electrical precipitators before the design of the control system is formulated. General design information on electrical precipitators has been discussed in Chapter 4.

Water scrubbers

Water scrubbers have been used in many processes in which some contaminant must be removed from a gas stream. These same scrubbing methods have been used to control the emissions from electric-arc steel furnaces with varied results.

Table 74 shows the results of six tests on water scrubbers serving electric-arc steel-melting furnaces. Wet collectors collect only the larger particles and allow the submicron particles to pass through and be discharged to the atmosphere. These submicron particles cause the greatest diffusion of light and thus produce the greatest visual opacity. A venturi scrubber can be operated at greater efficiencies than those achieved by the scrubbers depicted in Table 74. A basic disadvantage of many scrubbers is that their efficiency of collection is proportional to their power input; thus, if a scrubber has the feature of high collection efficiency, the power input required to
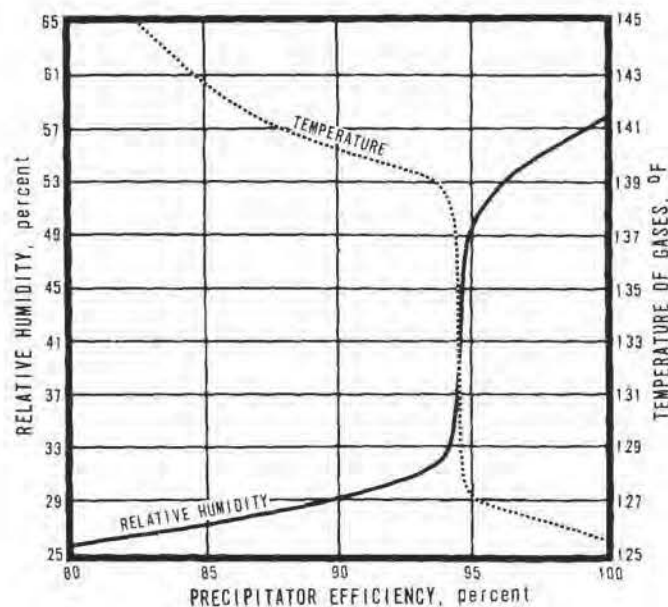
Figure 177. Curves showing effects of variation of the gas stream's temperature and humidity upon efficiency of a specific electrical-precipitator installation (Coulter, 1954).

realize this high efficiency is also large. In any event, the decision to install a scrubber over some other type of control device depends principally upon the collection efficiency required and the comparative costs of installation and operation.

ELECTRIC-INDUCTION FURNACE

The electric-induction furnace uses the material to be heated as a secondary of a transformer. When a high-frequency current is applied to the furnace coils, an electromagnetic field is set up in the core or space occupied by the metal to be melted. This high-density electromagnetic field induces currents in the metal, causing it to heat and melt. These furnaces range in size from 30 pounds' to 8 tons' capacity. They are not well adapted to a refining process and, for the most part, are used for preparation of special alloys, or for certified true heats, or for investment castings.

The Air Pollution Problem

The fume emissions from an electric-induction furnace processing steel alloys have the same characteristics as those from electric-arc furnaces. Since a high degree of control is exercised in preparing alloys in this type of furnace,

Table 73. OPERATING DATA OF ELECTRICAL-PRECIPITATOR CONTROL SYSTEMS SERVING ELECTRIC-ARC FURNACES
(Brief et al., 1956)

Case	A	B
Operational data		
Inlet gas volume, cfm	105,000	33,500
Inlet gas temperature, °F	127	80
Absolute humidity, lb/lb dry gas	0.045	Ambient
Inlet fume concentration, gr/ft^3	0.68[a] to 1.35[b]	0.115
Electrical-precipitator data		
Type	High-eff plate	Exp metal plate
Rectification	Mech, full wave	Mech, full wave
Size	30 ducts, 10 in. x 18 ft x 18 ft	19 ducts, 8-3/4 in. x 17 ft 6 in. x 18 ft
Gas velocity, fps	3.9	2.3
Gas retention time, sec	4.6	7.8
Electrode length	11,880	7,550
L/V ratio, $\dfrac{electrode\ length}{volumetric\ rate}$, sec/ft^2	6.8:1	13.6:1
Gas conditioner data		
Type	2-stage evaporative cooler	Radiation and tempering air cooler
Collection efficiency	97 + %	92%

[a]Average for one 50-ton and two 75-ton furnaces processing normal scrap.
[b]Average for one 50-ton and two 75-ton furnaces processing dirty, subquality scrap.

Table 74. HYDROSTATIC SCRUBBER DATA

Test	A	B	C	D	E	F
Total number of furnaces	2	1	1	2	1	1
Furnace size, tons	6 and 20	20	6	3 and 3	50	75
Process wt, lb/hr	12,444	4,720	6,240	5,020	27,200	43,900
Volume of gases inlet, scfm	17,500	22,700	20,700	10,140	25,900	32,400
Volume of gases outlet, scfm	20,600	24,600	20,700	10,860	29,800	35,600
Gas temperature inlet, °F	132	123	110	145	297	281
Gas temperature outlet, °F	89	76	92	92.5	99	105
Fume concentration inlet, gr/scf	0.158	0.0657	0.167	0.329	0.423	0.966
Fume concentration outlet, gr/scf	0.055	0.0441	0.102	0.108	0.109	0.551
Fume emission inlet, lb/hr	23.7	12.8	29.6	28.7	94	268
Fume emission outlet, lb/hr	9.71	9.3	13.2	10.1	27.8	168
Collection efficiency, %	59.1	27.3	55.4	65	70.4	37.3

metals contaminated with combustible elements such as rubber, grease, and so forth are not charged to the furnace. This practice eliminates the need for control of combustible contaminants. The quantity of contaminants emitted from induction furnaces processing steel alloys varies. The factors affecting the fume generation include composition of alloy, method of making the alloy addition, temperature of the melt, and size of the furnace. When these factors are controlled, some steel alloys can be made without the need of air pollution control equipment.

Hooding and Ventilation Requirements

Since induction furnaces are relatively small, the canopy-type hood is readily adaptable to capturing the fumes. Recommended hood indraft velocities vary from 200 to 500 fpm, depending upon the hood, furnace geometry, cross-drafts, and temperatures involved. The following example problem shows a method of calculating ventilation requirements for a canopy-type hood serving an induction furnace:

Example 26

Given:

1,000-lb capacity electric-induction steel melting furnace

Pouring temperature = 3,000°F

Diameter of crucible = 2 ft

Surface area of molten metal = 3.14 ft^2

Hood height above furnace = 3 ft

Room air temperature = 100°F.

Problem:

Determine the minimum ventilation requirements for the furnace.

Solution:

$$q = 5.4 \, A_s \, (m)^{1/3} \, (\Delta t)^{5/12} \quad \text{(from Chapter 3)}$$

where

q = rate of thermal air motion at top of heat source, cfm

A_s = surface area of hot body and face area of hood, ft^2

m = diameter of crucible, ft. For lack of proved experimental values for m, the diameter of the molten metal (heat source) will be used in the operation

Δt = temperature differential between hot body and room air, °F.

$$q = (5.4)(3.14)(2)^{1/3}(2,900)^{5/12}$$

$$q = 590 \text{ cfm}$$

The formula used in calculating the ventilation requirements is accurate only for low-canopy hoods having an area equal to that of the heat source and having a maximum height of approximately 3 feet above the furnace. For high-canopy hoods, the hood area and ventilation volume must be increased.

Air Pollution Control Equipment

The design considerations for the remainder of the control system, including ductwork, type of collector, and fan and motor selection, are the same as outlined for electric-arc furnaces. Figure 178 is a photograph of two induction furnaces served by a canopy-type hood that vents to a baghouse.
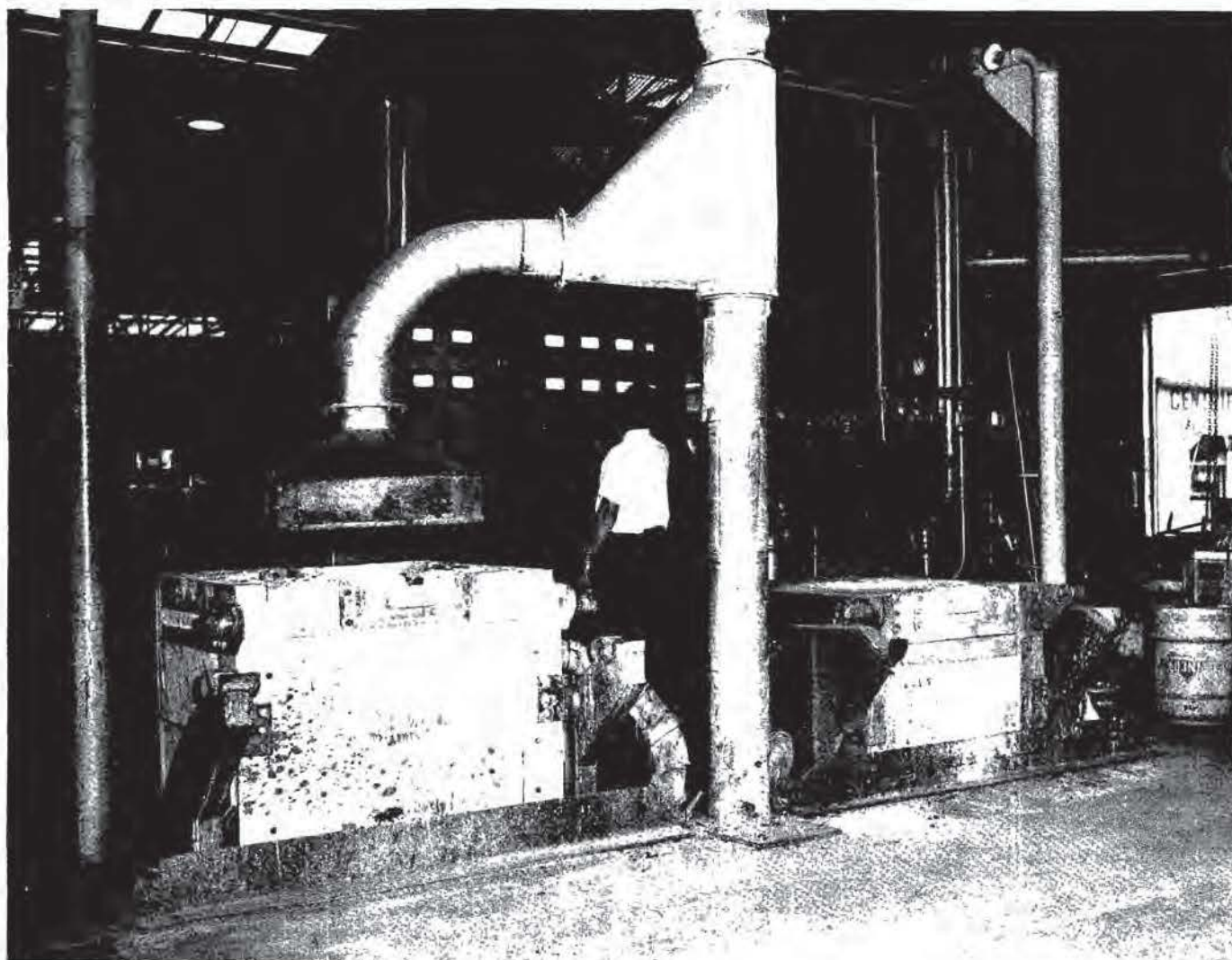
Figure 178. Canopy-type hood serving two electric-induction furnaces (Centrifugal Casting, Long Beach, Calif.).

IRON CASTING

Control of the air pollution that results from the melting and casting of iron may be conveniently considered according to the type of furnace employed. The cupola, electric, and reverberatory furnaces are the types most widely encountered. The air pollutants are similar, regardless of the furnace used; the primary differences among the air pollution control systems of the various furnace types are to be found in the variations in hooding, and the necessary preparation and treatment of the contaminated gases from the furnaces. Essentially, the air pollution problem becomes one of entraining the smoke, dust, and fumes at the furnace and transporting these contaminants to suitable collectors.

CUPOLA FURNACES

The most widely encountered piece of equipment in the gray iron industry is the cupola furnace. High production rates are possible and production costs per ton of metal are relatively low. Despite this, where the product permits, some gray iron foundries have substituted reverberatory furnaces for their cupolas rather than install the air pollution control equipment that cupolas require. Table 75 shows one manufacturer's recommendations for operating cupolas.

The Air Pollution Problem

Air contaminants emitted from cupola furnaces are (1) gases, (2) dust and fumes, and (3) smoke

Table 75. GENERAL RECOMMENDATIONS FOR OPERATING WHITING CUPOLAS
(Practical Hints on Cupola Operation, No. 237-R, Whiting Corporation, Harvey, Illinois)

Cupola size	Shell diameter, in.	Min. thickness of lower lining, in.[a]	Diameter inside lining, in.[a]	Area inside lining, in.[2]	Melting rate, tons/hr, with iron-coke (after bed) ratios of				Bed coke height above tuyeres,[b] in.	Coke and iron charges, lb					Lime-stone, lb	Air through tuyeres, cfm	Suggested blower selection[c]	
										Coke	Iron							
					6	8	10	12			6/1	8/1	10/1	12/1			cfm	Discharge pressure, oz
0	27	4-1/2	18	254	3/4	1			28 to 44	20	120	160			4	570	640	8
1	32	4-1/2	23	415	1	1-1/2			36 to 42	35	210	280			7	940	1,040	16
2	36	4-1/2	27	572	1-3/4	2-1/4			36 to 42	45	270	360			9	1,290	1,430	16
2-1/2	41	7	27	572	1-3/4	2-1/4			36 to 42	45	270	360			9	1,290	1,430	16
3	46	7	32	804	2-1/2	3-1/4	4		40 to 46	65	390	520	650		13	1,810	2,000	16
3-1/2	51	7	37	1,075	3-1/4	4-1/4	5-1/4		40 to 46	85	510	680	850		17	2,420	2,700	16 to 20
4	56	7	42	1,385	4	5-1/2	7		42 to 48	110	660	880	1,110		22	3,100	3,450	20 to 24
5	63	9	45	1,590	4-1/2	6-1/4	8		42 to 48	130	780	1,040	1,300		26	3,600	4,000	20 to 24
6	66	9	48	1,809	5-1/2	7-1/4	9	10-3/4	45 to 51	145	870	1,170	1,450	1,740	29	4,100	4,500	24 to 28
7	72	9	54	2,290	7	9-1/4	11-1/2	13-3/4	45 to 51	185	1,100	1,480	1,850	2,220	37	5,200	5,750	24 to 32
8	76	9	60	2,827	9	11-1/4	14	17	45 to 51	225	1,350	1,800	2,250	2,700	45	6,400	7,100	24 to 32
9	84	9	66	3,421	10-1/2	13-3/4	17	20-1/2	45 to 51	275	1,650	2,200	2,750	3,300	55	7,700	8,600	24 to 32
9-1/2	90	9	72	4,071	12-1/4	16-1/4	20-1/4	24-1/2	47 to 53	325	1,950	2,600	3,250	3,900	65	9,200	10,200	28 to 36
10	96		78	4,778	15	19	23-3/4	28-3/4	47 to 53	385	2,300	3,080	3,850	4,600	77	10,700	11,900	28 to 36
11	102	12	78	4,778	15	19	23-3/4	28-3/4	47 to 53	385	2,300	3,080	3,850	4,600	77	10,700	11,900	28 to 40
12	108	12	84	5,542	17	22-1/4	27-3/4	33-1/4	47 to 53	445	2,670	3,560	4,450	5,400	89	12,500	13,900	32 to 40

[a]For long heats, use heavier linings.
[b]Height of bed coke varies as square root of blast pressure. Recommend blowers with 20-oz discharge pressure when air weight control is used.
[c]Additional pressure capacity may be required when auxiliary equipment is added to the blast systems or when piping is long or complicated.

and oil vapor. The following is a typical cupola combustion gas analysis: Carbon dioxide, 12.2 percent; carbon monoxide, 11.2 percent; oxygen, 0.4 percent; nitrogen, 76.2 percent. Twenty to thirty percent by weight of the fumes are less than 5 microns in size. A particle size analysis of the dust and fumes collected from gray iron cupolas is shown in Table 76, as are some emission rates. Tables 77 and 78 show micromerograph and spectrographic particle size analysis of two samples taken from the hoppers of a bag filter serving a gray iron cupola furnace. Dust in the discharge gases arises from dirt on the metal charge and from fines in the coke and limestone charge. Smoke and oil vapor arise primarily from the partial combustion and distillation of oil from greasy scrap charged to the furnace.

Hooding and Ventilation Requirements

One way to capture the contaminants discharged from a cupola furnace is to seal the cupola top and vent all the gases to a control system. A second method is to provide a vent in the side of the cupola a few feet below the top of the burden and vent the gases to a control system. The control system consists of an afterburner, a gas-

cooling device, and a dust collector, which is either a baghouse or an electrical precipitator. The system must be designed to exhaust enough gas volume to remove all the products of combustion from the cupola and to inspirate sufficient air at the charge opening to prevent cupola gas discharge at that point. In addition, the exhaust gas volume must be sufficient to remove the products of combustion from the afterburner section. In cupolas of large diameter (over 36 in.), enclosure of the charge opening with refractory-lined or water-cooled doors is usually necessary. These doors are pneumatically operated to open only during the actual dumping of a charge into the cupola.

Even though a closed top cupola is equipped with a door to cover the charge opening, it is common practice to design the ventilation unit to provide at least 250 fpm average indraft velocity across the full open area of the charge opening.

Air Pollution Control Equipment

Collection efficiencies of several small-scale control devices on gray iron cupolas are shown in

Table 76. DUST AND FUME EMISSIONS FROM GRAY IRON CUPOLAS

Test No.	1	2	3	4	5	6	7
Cupola data							
Inside diameter, in.	60	37	63	56	42	60	48
Tuyere air, scfm	-	1,950	7,500	-	-	-	-
Iron-coke ratio	7/1	6.66/1	10.1/1	6.5/1	9.2/1	9.6/1	7.4/1
Process, wt, lb/hr	8,200	8,380	39,100	24,650	14,000	36,900	16,800
Stack gas data							
Volume, scfm	8,300	5,520	30,500	17,700	20,300	21,000	8,430
Temperature, °F	1,085	1,400	213	210	430	222	482
CO_2, %	-	12.3	2.8	4.7	5.2	-	-
O_2, %	-	-	-	12.7	11.8	-	-
CO, %	-	-	-	0	0.1	-	-
N_2, %	-	-	-	67.5	67.3	-	-
Dust and fume data							
Type of control equipment	None	None	None	Baghouse	Elec precip afterburner	Baghouse	Elec Precip
Concentration, gr/scf							
Inlet	-	-	-	1.33	2.973	0.392	1.522
Outlet	0.913	1.32	0.413	0.051	0.0359	0.0456	0.186
Dust emission, lb/hr							
Inlet	-	-	-	197	184.7	70.6	110
Outlet	65	62.4	108	7.7	6.24	8.2	13.2
Control efficiency, %	-	-	-	96	96.6	88.4	87.7
Particle size, wt %							
0 to 5 μ	18.1	17.2	23.6	25.8	-	-	-
5 to 10 μ	6.8	8.5	4.5	6.3	-	-	-
10 to 20 μ	12.8	10.1	4.8	2.2	-	-	-
20 to 44 μ	32.9	17.3	9.5	10.0[a]	-	-	-
> 44 μ	29.3	46.9	57.9	55.7[b]	-	-	-
Specific gravity	3.34	2.78					

[a]From 20 to 50 μ.
[b]Greater than 50 μ.

Table 77. MICROMEROGRAPH PARTICLE SIZE ANALYSIS OF TWO SAMPLES TAKEN FROM A BAGHOUSE SERVING A GRAY IRON CUPOLA FURNACE

Sample A		Sample B	
Equivalent particle diameter, μ	Cumulative wt %	Equivalent particle diameter, μ	Cumulative wt %
0.9	0.0	1.0	0.0
1.1	1.3	1.3	1.7
1.4	3.4	1.6	3.6
1.8	7.4	2.1	7.0
2.3	11.6	2.6	10.5
2.8	15.0	3.0	13.3
3.7	20.4	4.2	19.9
4.6	24.6	5.2	24.8
5.5	27.3	6.3	29.0
6.4	29.0	7.3	32.5
6.9	29.8	7.8	34.9
7.3	30.3	8.4	36.3
7.8	30.7	8.9	38.6
8.2	31.2	9.4	39.8
8.7	31.3	10.1	41.1
9.3	31.9	10.4	42.0
10.1	32.1	10.9	43.2
11.0	33.1	12.5	45.4
12.4	33.5	14.1	46.7
13.7	33.6	15.6	47.0
16.5	33.9	18.8	47.4
19.3	34.2	21.9	47.6
22.0	34.4	25	47.7
24.7	34.7	28.1	48.0
27.5	35.1	31.3	48.4
30.2	36.0	34.4	48.8
34.4	37.5	39.1	49.8
41.3	40.6	46.9	52.3
55.0	46.4	62.5	56.7
68.7	51.1	78.1	63.4
82.6	55.9	93.8	69.3
123	61.4	148	80.5

Table 78. QUALITATIVE SPECTROGRAPHIC ANALYSIS OF TWO SAMPLES TAKEN FROM A BAGHOUSE SERVING A GRAY IRON CUPOLA FURNACE[a]

Element	Approx amount, % Sample A	Approx amount, % Sample B
Aluminum	0.81	1.1
Antimony	0.24	0.24
Boron	0.050	0.054
Cadmium	0.13	0.064
Calcium	0.16	0.25
Chromium	0.022	0.019
Copper	0.42	0.32
Gallium	0.017	0.019
Germanium	0.018	0.015
Iron	6.0	7.5
Lead	17.0	17.0
Magnesium	0.29	0.30
Manganese	1.0	0.81
Molybdenum	0.0068	0.0075
Nickel	0.023	0.022
Potassium	1.5	1.2
Silicon	8.6	15.0
Silver	0.0093	0.0089
Tin	0.41	0.38
Titanium	0.019	0.034
Zinc	7.1	5.9

[a] These data are qualitative only and require supplementary quantitative analysis for actual amounts of the elements found to be present. These are the same samples as given in Table 77.

Table 79. These tests indicate the superior efficiencies of baghouses and electrical precipitators and, in practice, only these devices have been found to operate satisfactorily in Los Angeles County. As mentioned, these systems also include auxiliary items such as afterburners, gas-cooling devices, and settling chambers.

Afterburners

An afterburner is generally installed in a cupola furnace control system for two reasons. The high carbon monoxide content of the cupola effluent presents a definite explosion hazard; this hazard can be avoided by burning the carbon monoxide to carbon dioxide. Secondly, the afterburner burns combustion particulates, such as coke breeze and any smoke and oil vapors that may be distilled from the furnace charge. This combustion of oil vapors prevents later condensation on the surface of the filter bags and their resultant blinding. While afterburners may be installed as separate units, the common practice is to use the upper portion of the cupola between the charging door and the cupola top as the afterburner. When this is done, the height of the standard cupola must usually be increased to give a volume sufficient to provide adequate residence time to complete the combustion in the afterburner. As described earlier, the pollution problem from the various iron processes originates from emission of gases, dust, fumes, and smoke. The ratios of the quantities of the contaminants emitted from this equipment vary appreciably and influence the selection of the control device or devices to be employed.

An afterburner should be designed with heat capacity to raise the temperature of the combustibles, inspirated air, and cupola gases to at least 1,200°F. The geometry of the secondary combustion zone should be such that the products to be incinerated have a retention time of at least 1/4 second. A luminous flame burner is desirable, since it presents more flame exposure. Enough turbulence must be created in the gas stream for thorough mixing of combustibles and air. In large-diameter cupola furnaces, stratification of the gas stream may make this a major problem. One device, proved successful in promoting mixing in large-diameter cupolas, is the inverted cone shown in Figure 179. The combustion air is inspirated through the charging door and, if necessary, may also be inspirated through openings strategically located in the cupola circumference, above the charging opening. The

Table 79. SOME COLLECTION EFFICIENCIES OF EXPERIMENTAL SMALL-
SCALE CONTROL DEVICES TESTED ON GRAY IRON CUPOLAS[a]

Equipment tested	Inlet gas volume, scfm	Outlet gas volume, scfm	Inlet dust load, gr/scf	Outlet dust load, gr/scf	Collection efficiency, %	Remarks
Controls for cupolas[b]						
High-efficiency cyclone	330	384	1.225	0.826	22.5	
Dynamic water scrubber	1,410	1,760	1.06	0.522	38.2	Water added before control unit for cooling totalled 6 gpm
Venturi-type scrubber	375	432	1.17	0.291	71.3	Two gpm water introduced for cooling gas stream; 3.5 gpm added at venturi throat; cyclonic scrubber operated dry
Dynamic--impingement wet scrubber	605	995	0.95	0.141	75.6	Water rate in excess of 10 gpm
Baghouse--one silicone-treated glass wool bag, 10 in. dia x 10 ft length	52.7	52.7	1.32	0.046	96.5	Average temp, 372°F, average filtering velocity, 3.22 gpm
Evaporative cooler and redwood pipe electrical precipitator	1,160	1,330	1.263	0.0289	97.7	Water rate to cooler, 22 gpm; to precipitator, 2 gpm
Other basic equipment						
Natural gas-fired reverberatory furnace	--	5,160	--	0.00288	96.2[c]	Melting rate, 546 lb/hr; gas consumption rate, 4,200 cfh; melting clean scrap and pig iron

[a] In all cases, equipment was installed and operated according to the manufacturer's recommendations.
[b] The six control devices were tested on the same cupola.
[c] This is not an actual collection efficiency, but a percent reduction when compared with average cupola emissions.

rapid ignition of the combustible effluent by the afterburner frequently results in a pulsating or puffing emission discharge from the charging door. This can be eliminated by the installation of an ignition burner below the level of the charging door, which ignites and partially burns the combustible effluent.

A cupola afterburner need not be operated through the entire furnace cycle. Even without an afterburner, an active flame can be maintained in the upper portion of the cupola. This requires control of the materials charged, and likewise, control of combustion air and mixing. The afterburner must, however, be in operation during the furnace light-off procedure. It is desirable to ignite the coke bed with gas torches, because considerable smoke may result if the light-off is done with kindling wood.

Baghouse dust collectors

The temperature of the gas stream discharged from the top of a cupola may be as high as 2,200°F. If a baghouse is used as a control device, these gases must be cooled to prevent burning or scorching of the cloth bags. Maximum temperatures allowed vary from 180°F for cotton bags to 500°F for glass fabric bags.

Cooling can be effected by radiant cooling columns, evaporative water coolers, or by dilution with ambient air. Figure 180 shows an installation in which the gas stream is cooled by dilution and ra-

diation-convection cooling columns. Of the three types of coolers, spraying is the most common. All types have been discussed in Chapter 3.

For satisfactory baghouse operation, when metallurgical fumes are to be collected, filtering velocity should not exceed 2-1/2 fpm. Provisions for cleaning collected material from the bags usually require compartmentation of the baghouse so that one section of the baghouse may be isolated and the bags shaken while the remainder of the system is in operation. The gas temperature through the baghouse should not be allowed to fall below the dew point, because condensation within the baghouse may cause the particles on the bag surfaces to agglomerate, deteriorate the cloth, and corrode the baghouse enclosure. A bypass control must also be installed. If the cooling system fails, the bypass is opened, which discharges the effluent gas stream to the atmosphere and thus prevents damage to the bags from excessive temperatures. Properly designed and maintained baghouses can normally be expected to have efficiencies ranging upwards from 95 percent.

Electrical precipitators

Electrical precipitators are an efficient control device for collecting most metallurgical fumes where steady-state conditions of temperature and humidity can be maintained in the gases to be cleaned. The procedures used in determining the effluent gas volume and temperatures for a precipitator
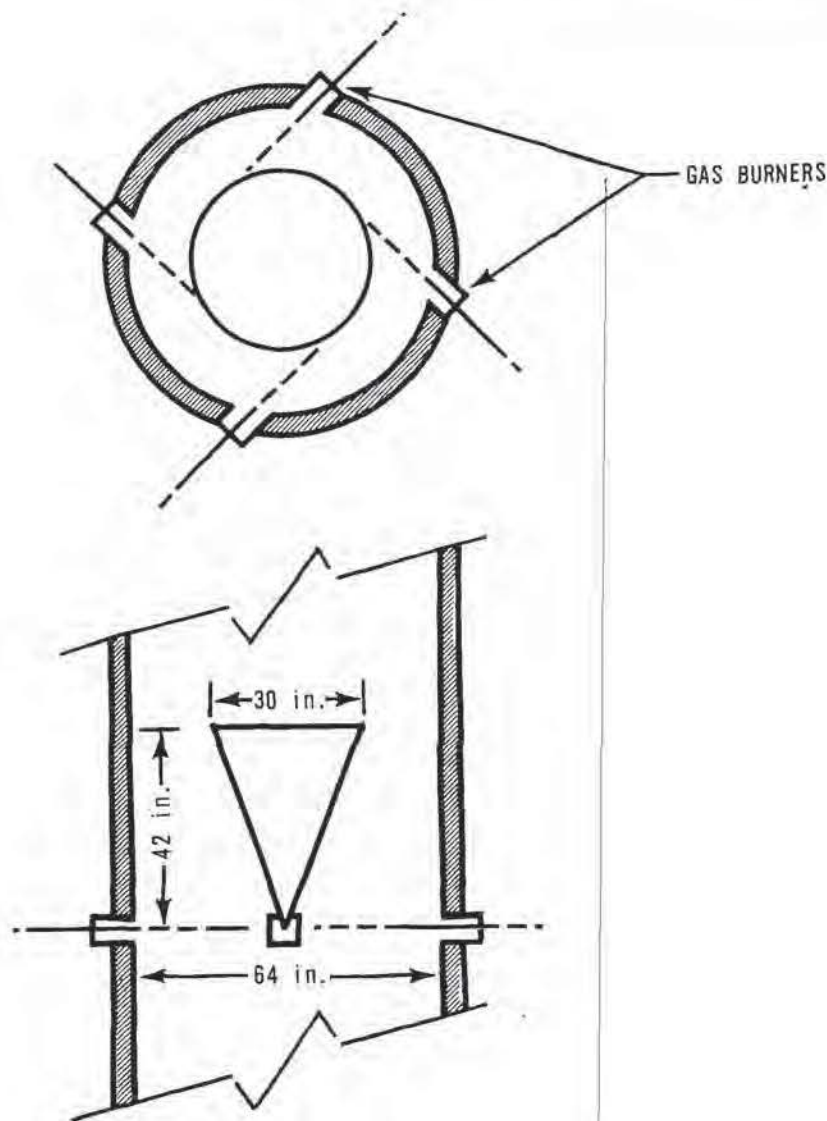
Figure 179. Integral afterburner with inverted cone installed in top part of cupola to create turbulence to ensure complete combustion.

control system are the same as those for a bag-house control system. The collection efficiency of an electrical precipitator depends in part upon the apparent resistivity of the material to be collected. This, in turn, depends upon the characteristics of the material, and the moisture content and temperature of the effluent gas stream. After the condition of the gas stream under which precipitation is to take place has been determined, the system's conditioning units for controlling the temperature and humidity of the effluent gas stream can be designed. The large temperature fluctuations of the effluent gas stream from a cupola require that the control system be designed to maintain proper levels of temperature and humidity. Installation and operation of equipment to main-

tain these levels may be bulky and expensive, and should be reviewed with the manufacturer. In order to avoid corrosion in the precipitator unit, the control system must be designed to prevent water carryover or condensation. Figure 181 shows a cylindrical water spray conditioning chamber, upper left; electrical precipitator, center; fan and discharge duct, upper right. These control units vent a cupola with a separate afterburner, not shown in the photograph. The precipitator rectifier is housed in the concrete block building in the foreground.

Additional design information on electrical precipitators has been presented in Chapter 4.

Figure 180. Cupola controlled by radiation convection coolers and baghouse (Alhambra Foundry Company, Alhambra, Calif.).

Cupola data

Size, 45-in. ID
Flue gas vol, 7,980 scfm
Tuyere air, 3,450 scfm

Iron - coke ratio, 8:1
Flue gas temp, 1,875° to 2,150°F
Charging rate, 20,200 lb/hr

Gas conditioner data

Radiation and convection type
Cooling area, 10,980 ft²
Log mean temp diff, 670 °F
Heat trans coef, 1.59 Btu/hr-ft² per °F

Gas vol (incl recirculation), 16,100 scfm
Size, 16 col 42-in. dia x 42-ft. H
Inlet gas temp, 1,030°F
Outlet gas temp, 404°F

Baghouse data

Tubular and compartmented type
Inlet gas volume, 13,100 cfm
Filter area, 4,835 ft²
Filter media, silicone glass
Shaking cycle, 90 min (manual by
    compartment)

Collection efficiency, 99+%
Tube size, 11-in. dia x 180-in. L
Inlet gas temp, 404°F
Filtering velocity, 2.7 fpm
Pressure drop, 3 to 4 in. WC

Illustrative Problem

The following example shows some of the factors that must be considered in designing a control system for a gray iron cupola furnace (Figure 182).

Example 27

Given:

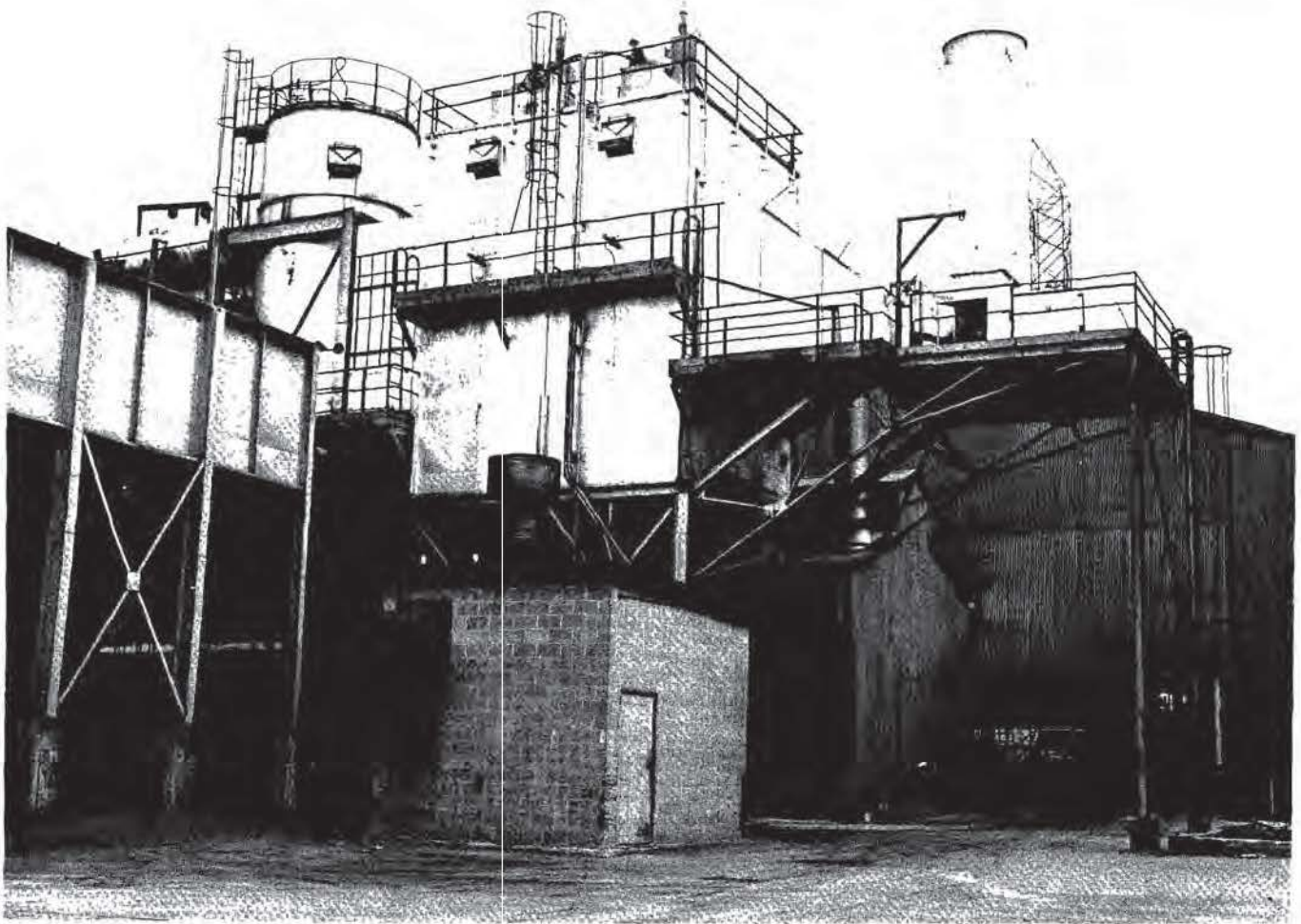A 32-in.-ID cupola

Charging door area, 4.5 ft²

Figure 181. Photograph of an electrical precipitator preceded by a water spray conditioning chamber; vented cupola and afterburner not shown (Alabama Pipe Company, South Gate, Calif.).

Cupola data

Size, 42-in. ID
Flue gas vol, 8,700 scfm
Tuyere air, 3,000 cfm

Flue gas temp, 400° to 1,400°F
Iron - coke ratio, 9.2:1
Charging rate, 14,000 lb/hr

Afterburner data

Type of structure--an unused cupola furnace converted by the installation of four premix gas burners with full modulating temperature controls to maintain 1,100°F minimum outlet temperature. Fuel input, 10 million Btu/hr maximum

Gas conditioner data

Evaporator cooler type
Water rate, 75 gpm (max)

Gas temp inlet, 1,100°F min.
Size, 10-ft 6-in. dia x 23-ft 6-in. length

Electrical precipitator data

Type, expanded metal
Collecting electrode, size, 17 ft 6 in. x 4 ft 6 in.
Discharge electrode, 0.109-in. dia
Gas volume, 20,300 scfm
Outlet dust loss, 0.0359 gr/scf

No. of sections, 2 in series
Size, 23 ducts 8-3/4 in. x 17 ft 6 in. x 9 ft
Average gas temp, 430°F
% Moisture in flue gas, 15%
Overall efficiency, 96.6

Tuyere air, 1,810 scfm

Maximum gas temperature at cupola outlet, 2,000°F.

Minimum incineration temperature to be maintained at cupola outlet, 1,200°F.

Assume a closely coupled unit from the cupola to the evaporative cooling chamber and an insulated duct between the evaporative cooling chamber and the baghouse.

Assume the effluent gases have the same properties as air. (Consideration of the enthalpies and
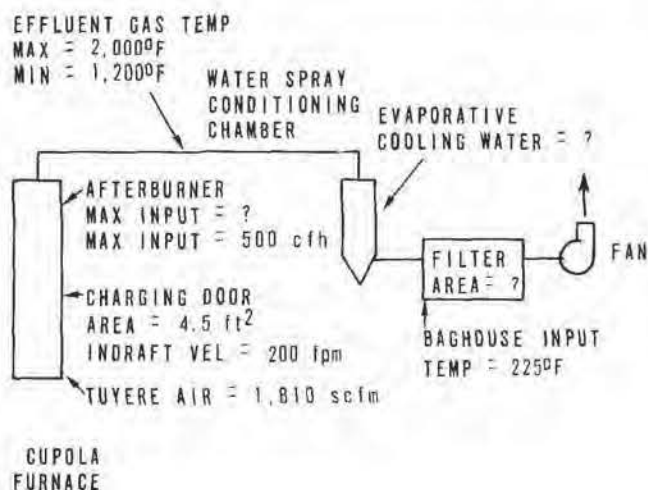
EFFLUENT GAS TEMP
MAX = 2,000°F
MIN = 1,200°F   WATER SPRAY
               CONDITIONING
               CHAMBER   EVAPORATIVE
                         COOLING WATER = ?

AFTERBURNER
MAX INPUT = ?
MAX INPUT = 500 cfh

FILTER
AREA = ?   FAN

CHARGING DOOR
AREA = 4.5 ft²
INDRAFT VEL = 200 fpm

BAGHOUSE INPUT
TEMP = 225°F

TUYERE AIR = 1,810 scfm

CUPOLA
FURNACE

Figure 182. Control system for a gray iron
cupola furnace.

specific heats of the gaseous constituents in the
effluent gas stream will show that this is an ac-
curate assumption. Any corrections would intro-
duce an insignificant refinement to the calculations
when considered with respect to the accuracy of
other design factors.)

Problem:

Determine the design features of an evaporative
cooling system and a baghouse to serve the cupola.

Solution:

1. Volume of gases from tuyeres = 1,810 scfm
    or 139.3 lb/min

2. Heat required from afterburner to raise tem-
    perature of tuyere air products of combustion
    from an assumed low of 500°F to a minimum
    incineration temperature of 1,200°F:

    Enthalpy of gas (1,200°F) = 287.2 Btu/lb
    (see Table D3 in Appen-
    dix D)

    Enthalpy of gas (500°F)   = 106.7 Btu/lb
                          Δh = 180.5

    (139.3)(180.5)   = 25,150 Btu/min

3. Heat required from afterburner to raise charg-
    ing door indraft air from 60° to 1,200°F:

    Assume a charging door indraft velocity of
    200 fpm, which will be adequate to ensure an
    indraft of air at all times.

    Charge door indraft volume = (4.5)(200) =
    900 scfm or 69.3 lb/min

    Enthalpy of gas (1,200°F) = 287.2 Btu/lb

    Enthalpy of gas (60°F)   =   0
                        Δh = 287.2

    (69.3)(287.2)   = 19,900 Btu/min

4. Total heat to be supplied by afterburner:

    Heat to tuyere air   = 25,150 Btu/min
    Heat to charge door
    indraft volume   = 19,900 Btu/min
              Total   45,050 Btu/min

5. Required natural gas volume capacity of after-
    burner to supply 45,050 Btu/min:

    Heating value of gas = 1,100 Btu/ft³

    Heat available at 1,200°F, from the burning
    of 1 ft³ of gas with theoretical air = 721.3
    Btu/ft³ (see Table D7 in Appendix D)

    $\frac{45,050}{721.3}$ = 62.4 cfm

6. Volume of products of combustion from after-
    burner:

    With theoretical air, 1 ft³ of gas yields 11.45
    ft³ of products of combustion (see Table D7
    in Appendix D)

    (62.4)(11.45) = 715 cfm

7. Total volume of products to be vented from
    cupola, scfm:

    Volume from tuyere air   = 1,810

Volume for charge door
indraft $=$ 900

Volume from afterburner $=$ $\dfrac{715}{3,425 \text{ scfm}}$

         or   264 lb/min

8. Volume of vented gases at 1,200°F:

$$(3,425)\left(\frac{1,200+460}{60+460}\right) = 10,900 \text{ cfm}$$

9. Duct diameter from cupola exit to evaporative chamber:

Use design velocity of 3,500 fpm

Duct cross-sectional area $= \dfrac{10,900}{3,500} = 3.12 \text{ ft}^2$

    ∴ Use 24-in.-dia. duct

10. Cooling required to reduce temperature of vented products from cupola from 1,200° to 225°F:

Baghouse inlet design temperature taken as 225°F

Enthalpy of gas at 1,200°F $= 287.2$ Btu/lb

Enthalpy of gas at 225°F $\;\;= 39.6$ Btu/lb

             Δh $= 247.6$ Btu/lb

$$(264)(247.6) = 65,300 \text{ Btu/min}$$

11. Water to be evaporated to cool vented gas products from 1,200° to 225°F:

Heat absorbed per lb of water:

$Q = h_g$ (225°F, 14.7 psia) - h_f (60°F)

    $= 1,156.8 - 28.06 = 1,128.74$ Btu/lb H_2O

$\dfrac{65,300}{1,128.74} = 58.0$ lb H_2O/min

12. Volume of evaporated cooling water at 225°F:

$v = 27.36$ ft^3/lb H_2O (14.7 psia, 225°F)

$$(58.0)(27.36) = 1,586 \text{ cfm}$$

13. Total volume of products vented from spray chamber:

Volume of products from
cupola $= 3,425$ scfm

Volume of evaporated
cooling water $= 1,586$ cfm (225°F)

$$(3,425)\left(\frac{225+460}{60+460}\right) + 1,586 = 6,106 \text{ cfm}$$

14. Duct diameter between spray chamber and baghouse:

Use design velocity of 3,500 fpm

$$\frac{6,106}{3,500} = 1.745 \text{ ft}^2$$

    ∴ Use an 18-in.-dia. duct

15. Required filter area of baghouse:

Design for a filtering velocity of 2 fpm

$$\frac{6,106}{2} = 3,053 \text{ ft}^2$$

During burndown, the cupola discharge gases will increase in temperature to 2,000°F and the afterburner input will be reduced to the low fire settling at an input of 500 ft^3 of gas per hr (8.33 cfm). Calculations will be made under this new operating condition to determine whether the previously calculated values for duct sizes, evaporative water quantity, and filter area are compatible.

16. Volume of products of combustion from afterburner:

$$(8.33)(11.45) = 95.5 \text{ cfm}$$

17. Total volume of products to be vented from cupola:

Volume from tuyere air $= 1,810$

Volume from charge door indraft $=$ 900

Volume from afterburner $= \dfrac{95.5}{2,805.5 \text{ scfm}}$

      or   216 lb/min

18. Volume of vented gases at 2,000°F:

$$(2,805.5)\left(\frac{2,000+460}{60+460}\right) = 13,280 \text{ cfm}$$

19. Gas velocity between cupola and spray chamber when using 24-in. duct from calculation 9:

$$\frac{13,280}{3,142} = 4,230 \text{ fpm}$$

Velocity is greater than necessary but not excessive.

20. Cooling required to reduce temperature of vented products from cupola from 2,000° to 225°F:

Enthalpy of gas at 2,000°F = 509.5 Btu/lb
Enthalpy of gas at   225°F = $\underline{39.6 \text{ Btu/lb}}$

$$\Delta h = 469.9 \text{ Btu/lb}$$

$$(216)(469.9) = 101,300 \text{ Btu/min}$$

21. Water to be evaporated to cool vented gas products from 2,000° to 225°F:

Heat absorbed per lb of water = 1,128.74 Btu/lb (see calculation 11)

$$\frac{101,300}{1,128.74} = 90 \text{ lb } H_2O/\text{min}$$

This is greater than that determined in calculation 11 and must therefore be taken as the design value.

22. Volume of evaporated cooling water at 225°F:

$$v = 27.36 \text{ ft}^3/\text{lb } H_2O \ (14.7 \text{ psia}, 225°F)$$

$$(90)(27.36) = 2,460 \text{ cfm}$$

23. Total volume of products vented from spray chamber:

Volume of products from
cupola   = 2,805.5 scfm
Volume of evaporated
cooling water   = 2,460 cfm (225°F)

$$(2,805.5)\left(\frac{225 + 460}{60 + 460}\right) + 2,460 = 6,160 \text{ cfm}$$

24. Gas velocity between spray chamber and baghouse using 18-in. duct from calculation 14:

$$\frac{6,160}{1.767} = 3,480 \text{ fpm}$$

Velocity is comparable with design value of 3,500 fpm

25. Filtering velocity using filter area from calculation 15:

$$\frac{6,160}{3,053} = 2.02 \text{ fpm}$$

This ratio is in agreement with a filtering velocity of 2 fpm

26. The exhaust system and fan calculations are made as outlined in Chapter 3. After a system resistance curve has been calculated and plotted, a fan is selected whose characteristic curve will intersect the system curve at the required air volume, which for this example would be 6,160 cfm.

Problem note: This example problem illustrates typical calculations that can be followed in designing a cupola control system. Each installation must be evaluated separately, considering expected maximum and minimum temperatures, gas volumes, duct lengths, and so forth. For example, this problem was patterned after a small cupola where the charging door remains open. For large cupolas, opening and closing the charging doors must be evaluated relative to its effect upon gas volumes and temperatures. If duct runs are long, the radiation-convection losses may be worth considering. The sizing of the fan motor depends upon the weight of gas moved per unit time. This in turn depends upon the density (considering air, water vapor, and temperature) of the gas stream. These items are taken into consideration in making the exhaust system resistance calculations. It may be necessary to reduce the system's airflow by dampering in order to prevent overloading of the fan motor when making a cold startup under ambient conditions. See Chapter 3 for design parameters for cooling of effluent gas stream with radiation-convection cooling columns. Since the temperature of the effluent gas stream from the cupola will fall in the range of 1,200° to 2,000°F, the duct connecting the cupola and water spray conditioning chamber should be made of stainless steel or be refractory lined.

ELECTRIC-ARC FURNACES

Electric-arc furnaces are commonly used in the secondary melting of iron where special alloys are to be made. These furnaces may be either the direct- or indirect-arc type. Pig iron and scrap iron are charged to the furnace and melted, and alloying elements and fluxes are added at specified intervals. These furnaces have the advantage of rapid and accurate heat control.

The Air Pollution Problem

Since no gases are used in the heating process, some undesirable effects on the metal are eliminated. Since arc furnaces in the iron industry are virtually always used to prepare special alloy irons, the quality of the material charged is closely controlled. The charging of greasy scrap, which would emit combustible air contaminants, would only needlessly complicate the alloying procedure. Afterburners are, therefore, rarely required in conjunction with arc furnace operations. The emissions consist, primarily, of metallurgical fumes and can be controlled by either a baghouse or an electrical precipitator. The emission rates from electric-arc furnaces vary according to the process from 5 to 10 pounds per ton of metal processed.

Hooding and Ventilation Requirements

Direct-arc furnaces for melting gray iron present a unique and difficult problem of hooding. The hood's geometry and the indraft velocity must be designed to ensure virtually complete collection of the emissions from the furnace. Hood design varies considerably for different furnaces. Furnaces are most successfully hooded by building the hood into the cover or top of the furnace. This, of course, means designing an air chamber or compartment above the furnace roof and providing a duct connection to the chamber so that the collected contaminants may be vented to the control device. Since direct-arc furnaces receive only a limited use for melting cast iron, generalizing about the ventilation requriements is difficult; however, 5,000 to 7,500 cfm per ton of production apparently yields a reasonable degree of dust and fume capture. To be most effective, the ventilation air exhausted from the furnace should also be available to the furnace hood during periods of tapping and charging the furnace. This means that some type of telescoping ductwork or slip-connection ductwork must form the connection between the control device and the hood. Figure 183 illustrates an adjustable-type hood used with a baghouse venting rocking-arc furnaces. The hood is positioned by means of a telescoping connection that is mechanically controlled. In the right foreground of the photograph, the hood is shown lowered into position with the furnace in operation, while in the left background, the hood is shown raised from the furnace to facilitate charging and furnace access.

Air Pollution Control Equipment

Baghouse dust collectors

Elaborate facilities for cooling the effluent gas stream from an electric furnace may not be necessary for two reasons: (1) No products of combustion result from the burning of fuel, and (2) canopy-type or roof-type hoods are generally used. Thus, the volume of the effluent gas stream is low, and the ventilation air drawn in at the hood provides cooling. As with cupola baghouses, a filtering velocity of 2-1/2 fpm should not be exceeded and a shaking mechanism and compartmentation must be provided.

Electrical precipitators

As in the case of baghouse dust collectors serving electric-arc furnaces, no elaborate facilities are necessary for cooling the effluent gas stream from an electric furnace vented to an electrical precipitator, though the design humidity and temperature of gases entering the electrical precipitator must be met. This may require water spray sections or afterburner devices to heat and humidify the gases vented to the precipitator.

INDUCTION FURNACES

Core-type electric-induction furnaces are also used for melting cast iron. In this type of furnace, alternating current is passed through a primary coil with a solid iron core. The molten iron contained within a loop that surrounds the primary coil acts as the secondary. The alternating current that flows through the primary induces a current in the loop, and the electrical resistance of the molten metal creates the heat for melting. The heated metal circulates to the main furnace chamber and is replaced by cooler metal. This circulation results in uniform metal temperature and alloy composition.

The electric-induction furnace generates considerably smaller amounts of air contaminants than the cupola or electric-arc furnace does; the amount is mainly dependent upon the condition of the metal charged. When pig iron and clean casting returns are charged, no air pollution control equipment is necessary for ordinary melting. Contaminated scrap or the addition of magnesium for manufacturing ductile iron would, however, necessitate air pollution control equipment. In cases such as these, design requirements for a baghouse control system with canopy-type hooding are the same as later described in this chapter for coreless induction furnaces for steel melting.

REVERBERATORY FURNACES

Small reverberatory furnaces are also used in preparing gray and white cast iron alloys. If clean metal is charged to these furnaces, no excessive air pollution results from their use. Figure 184 shows a small, gas-fired, reverberatory
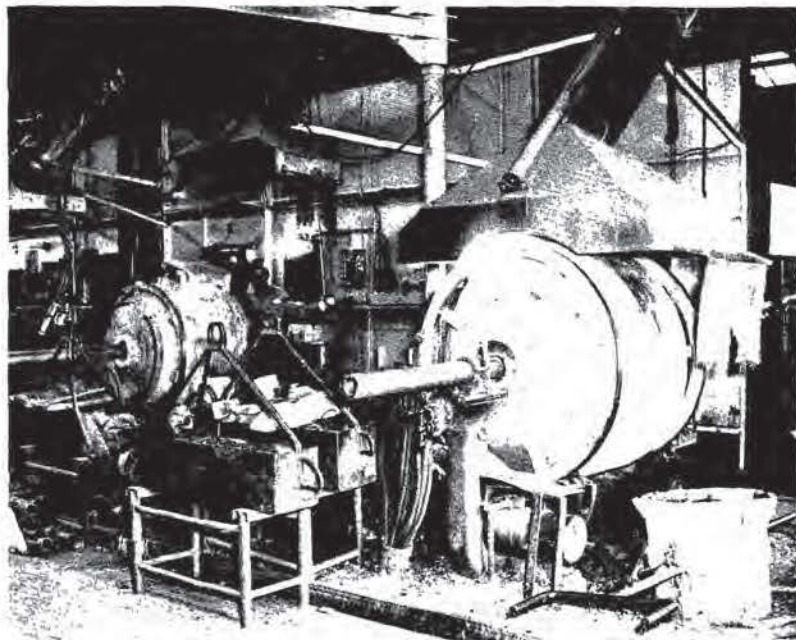
Figure 183.   Rocking-arc furnaces venting through adjustable hoods to a baghouse
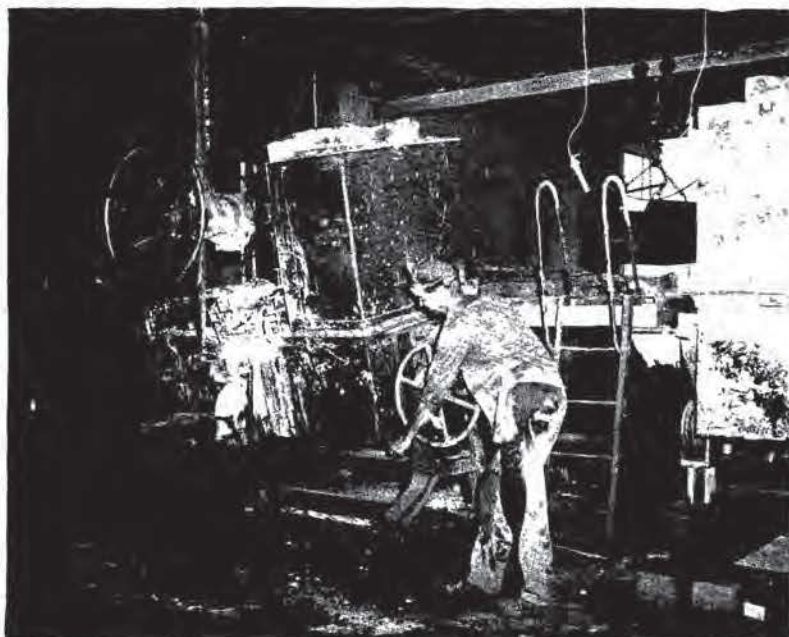(Centrifugal Casting Company, Long Beach, Calif.).

Figure 184.   Gray iron reverberatory furnace (Pomona Foundry, Pomona, Calif.).

Reverberatory furnace data

Rated capacity, 1,000 lb
Fuel, natural gas
Furnace flue gases, calculated at
    6,100 cfm at 2,850°F
Pouring temp, 2,700°F

Typical charge, 300 lb pig iron, 500 lb
    scrap iron, 200 lb foundry returns,
    2 lb soda ash
Melting rate, 750 lb/hr
Fuel rate, 4,200 ft^3/hr

Test data

Gas volume at hood, 5,160 scfm
Dust loss in gr/scf, 0.00278

Average gas temp, 775°F
Loss in lb/hr, 0.13

furnace used in a gray iron foundry. Test results made upon a furnace of this type, rated at 1,000-pounds capacity, while it was melting clean scrap iron and pig iron, showed a particulate loss to the atmosphere of 0.00275 grain per standard cubic foot, or 0.14 pound per hour. Because of this low rate of particulate discharge, no air pollution control devices have been found necessary for the operations conducted in this type of furnace melting iron.

SECONDARY BRASS- AND BRONZE-MELTING PROCESSES

Copper when alloyed with zinc is usually termed brass, and when alloyed with tin is termed bronze. Other copper alloys are identified by the alloying metals such as aluminum bronze and silicon bronze. The true bronzes should not be confused with some other common classifications of bronzes, which are actually misnomers. For example, "commercial bronze" is a wrought red brass, and "manganese bronze" is a high-zinc brass. Because of high strength, workability, corrosion resistance, color, and other desirable physical characteristics, the copper-base alloys have found wide use for hardware, radiator cores, condensers, jewelry, musical instruments, plumbing fittings, electrical equipment, ship propellers, and many other devices.

The remelting of nearly pure copper and bronze does not have great interest from the standpoint of air pollution since only small amounts of metal are volatilized. This is due to the high boiling points of copper and tin (above 4,000°F) and their low normal pouring temperatures of about 2,000° to 2,200°F. With good melting practice, total emissions to the air should not exceed 0.5 percent of the process weight. The brasses containing 15 to 40 percent zinc, however, are poured at temperatures near their boiling points (about 2,200°F), and some vaporization or combustion of desirable elements, particularly zinc, is inevitable. Emissions into the air may vary from less than 0.5 percent to 6 percent or more of the total metal charge (St. John, 1955) and 2 to 15 percent of the zinc content through fuming (Allen et al., 1952), depending upon the composition of the alloy, the type of furnace used, and the melting practice.

FURNACE TYPES

Brass and bronze shapes for working, such as slabs and billets, are usually produced in large gas- and oil-fired furnaces of the reverberatory type. Most operators of secondary smelters also use this type of furnace for reclaiming and refining scrap metal, ordinarily casting the purified metal into pigs. Brasses and bronzes used to make commercial castings are usually melted in low-frequency induction furnaces in the larger foundries and in crucible-type, fuel-fired furnaces in the smaller job foundries. Electric furnaces, both arc and induction, are also used for castings. Generalizing in regard to the uses of various furnaces is difficult, since foundry practices are variable. A comparison of emissions from various types of furnaces is given in Table 80.

The Air Pollution Problem

Air contaminants emitted from brass furnaces consist of products of combustion from the fuel, and particulate matter in the form of dusts and metallic fumes. The particulate matter comprising the dust and fume load varies according to the fuel, alloy composition, melting temperature, type of furnace, and many operating factors. In addition to the ordinary solid particulate matter, such as fly ash, carbon, and mechanically produced dust, the furnace emissions generally contain fumes resulting from condensation and oxidation of the more volatile elements, including zinc, lead, and others.

As was previously mentioned, air pollution resulting from the volatilization of metals during the melting of nearly pure copper and bronze is not too serious because of the high boiling-point temperatures of copper, tin, nickel, aluminum, and even lead commonly used in these alloys. Alloys containing zinc ranging up to 7 percent can be successfully processed with a minimum of fume emission when a cohesive, inert slag cover is used. This nominal figure is subject to some variation depending upon composition of alloy, temperatures, operation procedures, and other factors. Research is still necessary to determine the full range of effects these variables have upon the emission rate.

Copper-base alloys containing 20 to 40 percent zinc have low boiling points of approximately 2,100°F and melting temperatures of approximately 1,700° to 1,900°F. These zinc-rich alloys are poured at approximately 1,900° to 2,000°F, which is only slightly below their boiling points. Pure zinc melts at 787°F and boils at 1,663°F. Even within the pouring range, therefore, fractions of high-zinc alloys usually boil and flash to zinc oxide (Allen et al., 1952). The zinc oxide formed is submicron in size, and its escape to the atmosphere can be prevented only by collecting the fumes and using highly efficient air pollution control equipment.

Characteristics of emissions

Perhaps the best way to understand the difficulty of controlling metallic fumes from brass fur-

Table 80. DUST AND FUME DISCHARGE FROM BRASS FURNACES

Type of furnace	Composition of alloy, %					Type of control	Fuel	Pouring temp, °F	Process wt, lb/hr	Fume emission, lb/hr
	Cu	Zn	Pb	Sn	Other					
Rotary	85	5	5	5	-	None	Oil	No data	1,104	22.5
Rotary	76	14.7	4.7	3.4	0.67 Fe	None	Oil	No data	3,607	25
Rotary	85	5	5	5	-	Slag cover	Oil	No data	1,165	2.73
Elec ind	60	38	2	-	-	None	Elect	No data	1,530	3.47
Elec ind	71	28	-	1	-	None	Elect	No data	1,600	0.77
Elec ind	71	28	-	1	-	None	Elect	No data	1,500	0.54
Cyl reverb	87	4	0	8.4	0.6	None	Oil	No data	273	2.42
Cyl reverb	77	-	18	5	-	None	Oil	2,100	1,267	26.1
Cyl reverb	80	-	13	7	-	Slag cover	Oil	2,100	1,500	22.2
Cyl reverb	80	2	10	8	-	None	Oil	1,900 to 2,100	1,250	10.9
Crucible	65	35	-	-	-	None	Gas	2,100	470	8.67
Crucible	60	37	1.5	0.5	1	None	Gas	1,800	108	0.05
Crucible	77	12	6	3	2	Slag cover	Gas	No data	500	0.822

naces is to consider the physical characteristics of these fumes. The particle sizes of zinc oxide fumes vary from 0.03 to 0.3 micron. Electron photomicrographs of these fumes are shown in Figures 185 and 186. Lead oxide fumes, emitted from many brass alloys, are within this same range of particle sizes. The collection of these very small particles requires high-efficiency control devices. These metallic fumes also produce very opaque effluents, since particles of 0.2- to 0.6-micron diameter produce a maximum scattering of light.

In copper-base alloy foundries, as much as 98 percent of the particulate matter contained in furnace stack gases may be zinc oxide and lead oxide, depending upon the composition of the alloy. A series of tests (Allen et al., 1952) in Los Angeles County indicated the zinc oxide content of fume from representative red and yellow brass furnaces averaged 59 percent, while the lead oxide content averaged 15 percent. Other tests by the same investigators showed that the dust and fume loading from red and yellow brass furnaces varied from 0.022 to 0.771 grain per cubic foot with an average of 0.212 grain per cubic foot at stack conditions.

In high-lead alloys, these tests showed that lead oxide constituted 56 percent of the particulate matter in the exit gas. Lesser constituents of fumes, such as tin, copper, cadmium, silicon, and carbon, may also be present in varying amounts, depending upon the composition of the alloy and upon foundry practice.

Investigations prove conclusively that the most troublesome fumes consist of particles of zinc and lead compounds submicron in size, and that

air pollution control equipment capable of collecting particulate matter from 1.0 down to about 0.03 micron is required. Photomicrographs of samples taken when furnace emissions were heavy with smoke resulting from improper combustion or melting of oily scrap indicated that the smoke particles accompanying the fumes may be about 0.01 micron and smaller (Allen et al., 1952).

Factors causing large concentrations of zinc fumes

Four principal factors (Allen et al., 1952) causing relatively large concentrations of zinc fumes in brass furnace gases are:

1. Alloy composition. The rate of loss of zinc is approximately proportional to the zinc percentage in the alloy.

2. Pouring temperature. For a given percentage of zinc, an increase of 100°F increases the rate of loss of zinc about 3 times.

3. Type of furnace. Direct-fired furnaces produce larger fume concentrations than the crucible type does, other conditions being constant. The Los Angeles Nonferrous Foundrymen's Committee, 1948 stated, "It is improbable that any open-flame furnace melting alloys containing zinc and lead can be operated without creating excessive emissions. It is conceded that anyone choosing to operate that type of furnace will be required to install control equipment."

4. Poor foundry practice. Excessive emissions result from improper combustion, overheating of the charge, addition of zinc at maxi-

mum furnace temperature, flame impinge-
ment upon the metal charged, heating the
metal charged, heating the metal too fast,
and insufficient flux cover. Excessive super-
heating of the molten metal is to be avoided
for metallurgical and economic as well as
pollution control reasons. From an air pol-
lution viewpoint, the early addition of zinc is
preferable to gross additions at maximum
furnace temperatures.

In any fuel-fired furnace, the internal atmosphere
is of prime importance since there exists a con-
stant flow of combustion gases through the melt-
ing chamber, more or less in contact with the
metal. A reducing atmosphere is undesirable
from both the metallurgical and air pollution view-
points. With too little oxygen, the metal is ex-
posed to a reducing atmosphere of unburned fuel
and water vapor, which usually results in gassy
metal. Incomplete combustion, especially with

Figure 185.   Electron photomicrographs of fume from zinc smelter (Allen et al., 1952).
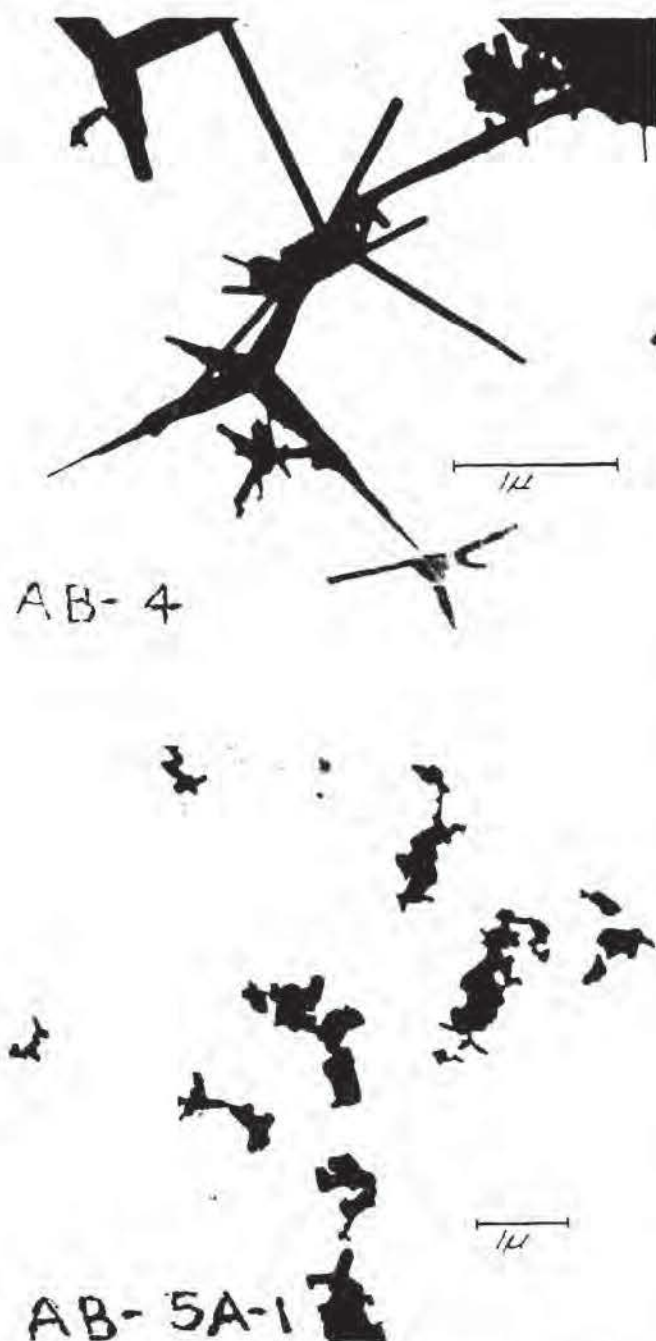
Figure 186. Electron photomicrographs of fume from a yellow brass furnace (Allen et al., 1952).

prevent excessive metal oxidation (St. John, 1955). The need for such close control of the internal furnace atmosphere requires careful regulation of the fuel and air input and frequent checking of the combustion gases.

Crucible furnace--pit and tilt type

The indirect-fired, crucible-type furnace is used extensively in foundries requiring small- and medium-sized melts. The lift-out-type crucible is frequently employed in small furnaces. Tests have demonstrated that, with careful practice and use of slag covers, the crucible furnace is capable of low-fume operation within the legal limits for red brasses containing as much as 7 percent zinc. A slag cover does not sufficiently suppress the emissions from alloys with a zinc content in excess of 7 percent unless very low pouring temperatures are used.

The slag cover, consisting mainly of crushed glass, is not used as a true refining flux but as an inert, cohesive slag of sufficient thickness to keep the molten metal covered. If the quantity of slag is carefully controlled, a minimum of emissions results from either melting or pouring. A slag thickness of 1/4 to 3/8 inch is recommended. Before any metal is added to the crucible, the flux should be added so that, as melting takes place, a cover is formed of sufficient thickness to keep the molten metal divorced from the atmosphere.

When the crucible of molten metal has reached the pouring floor, two holes are punched in the slag cover on top of the metal, one through which the metal is poured, the other to permit the entrance of air (Haley, 1949). Holding escaping oxides to a minimum is possible either by using patented attachments to hold back the slag at the pouring sprue or using a hand-operated skimmer.

Electric furnace--low-frequency induction type

The low-frequency, induction-type furnace has a number of desirable characteristics for melting brasses. The heating is rapid and uniform, and the metal temperature can be accurately controlled. Contamination from combustion gases is completely eliminated. High-frequency induction furnaces are well adapted to copper- and nickel-rich alloys but are not widely used for zinc-rich alloys. Low-frequency induction furnaces are more suitable for melting zinc-rich alloys. During melting of clean metal, use of a suitable flux cover over the metal prevents excessive fuming except during the back charging and pouring phases of the heat. The usual flux covers--borax, soda ash, and others--are destructive to furnace walls, but charcoal is used

oil firing, produces smoke and carbon. In one case, a furnace was operated with a fuel mixture so rich that incandescent carbon from the fuel ignited the cloth filter bags in the baghouse serving the furnace. To prevent these difficulties, the atmosphere should be slightly oxidizing. Excess oxygen content should be greater than 0.1 percent; otherwise, castings will be affected by gas porosity. Conversely, the excess oxygen content must be less than 0.5 percent to

with satisfactory results. During the test out-
lined in Table 81, case C, two-thirds of the total
fumes were released during the pouring and charg-
ing periods. A furnace, similar to that tested,
is shown in Figure 187.

Cupola furnace

The cupola furnace is used for reduction of cop-
per-base alloy slag and residues. The residues
charged have a recoverable metallic content of
25 to 30 percent. The balance of the unrecover-
able material consists of nonvolatile gangue,
mainly, silicates. In addition to the residues,
coke and flux are charged to the furnace. Period-
ically the recovered metal is tapped from the fur-
nace. The slag produced in the cupola is elim-
inated through a slag tap located slightly above
the metal tap.

In addition to the usual metallic fumes, the cupo-
la also discharges smoke and fly ash. Collec-
tion of these emissions is required at the cupola
stack, the charge door, and the metal tap spout.
With no control equipment, emissions of 60 to
100 percent opacity can be expected from the
charge door and stack. The opacity of the fumes
emitted from the metal tap varies from 60 to 80
percent.

The slag discharged from the cupola is rich in
zinc oxide. Although the slag leaves the furnace
at a temperature of approximately 1,900°F, the
zinc oxide is in solution and, at this tempera-
ture, does not volatilize to any extent. The dis-
charge slag is immediately cooled by water. The
emissions from the slag-tapping operation rarely
exceed 5 percent opacity.

Hooding and Ventilation Requirements

Regardless of the efficiency of the control device,
air pollution control is not complete unless all
the fumes generated by the furnace are captured.
Since different problems are encountered with the
various types of furnace, each will be discussed
separately.

Reverberatory furnace--open-hearth type

In a reverberatory open-hearth furnace, the prod-
ucts of combustion and metallic fumes are nor-
mally vented directly from the furnace through
a cooling device to a baghouse. Auxiliary hoods
are required over the charge door, rabble (or
slag) door, and tap hole. These may vent to the
baghouse serving the furnace and hence cool the
hot combustion gases by dilution or may vent to
a smaller auxiliary baghouse.

Table 81. BRASS-MELTING FURNACE AND BAGHOUSE COLLECTOR DATA

Case	A	B	C
Furnace data			
Type of furnace	Crucible	Crucible	Low-frequency induction
Fuel used	Gas	Gas	Electric
Metal melted	Yellow brass	Red brass	Red brass
Composition of metal melted, %			
Copper	70.6	85.9	82.9
Zinc	24.8	3.8	3.5
Tin	0.5	4.6	4.6
Lead	3.3	4.4	8.4
Other	0.8	1.3	0.6
Melting rate, lb/hr	388	343	1,600
Pouring temperature, °F	2,160	2,350	2,300
Slag cover thickness, in.	1/2	1/2	3/4
Slag cover material	Glass	Glass	Charcoal
Baghouse collector data			
Volume of gases, cfm	9,500	9,700	1,140
Type of baghouse	Sectional tubular	Sectional tubular	Sectional tubular
Filter material	Orlon	Orlon	Orlon
Filter area, ft^2	3,836	3,836	400
Filter velocity, fpm	2.47	2.53	2.85
Inlet fume emission rate, lb/hr	2.55	1.08	2.2[a]
Outlet fume emission rate, lb/hr	0.16	0.04	0.086
Collection efficiency, %	93.7	96.2	96.0

[a]Includes pouring and charging operations.

Figure 187.   Low-frequency induction furnace with fixed hood.

Whether the auxiliary hoods vent to the furnace baghouse or to a separate filter, the furnace burners should be turned down or off during periods when the furnace is opened for charging, rabbling, air lancing, removing slag, adding metal, or pouring metal.   Otherwise, the exhaust fan may not have sufficient capacity to handle the products of combustion and the additional air required to capture the fumes.   Since no two of these operations occur simultaneously, the required air volume for collection may be reduced by the use of properly placed dampers within the exhaust system.

If the entire furnace charge is made at the beginning of the heat, the metal should be loaded in such a way that the flame does not impinge directly upon the charge.   If periodic charges are made throughout the heat, the burners should be turned off during charging operations.   The opacity of escaping fumes may vary from none to 15 percent with the burners off and may be 60 to 70 percent with the burners ignited.

Well-designed hoods, properly located, with an indraft velocity of 100 to 200 fpm, adequately capture the furnace emissions.   If the hood is placed too high for complete capture or is improperly shaped and poorly fitted, higher indraft velocities are required.

The rabble or slag door permits (1) mixing the charge, (2) removing slag from the metal surface, and (3) lancing the metal with compressed air to eliminate iron from the metal when required by alloy specifications.   Emissions from the furnace may be of 50 to 90 percent opacity during these operations, even with the burners partially throttled.   Again, 100 to 200 fpm indraft velocity is recommended for properly designed hoods.

Generally, after the slag has been removed, metal, usually zinc, must be added to bring the brass within specifications.   The furnace metal is at a temperature well above the boiling point of zinc and is no longer covered by the tenacious slag

cover. Hence, voluminous emissions of zinc oxide result. The addition of slab zinc produces 100 percent opaque fumes in great quantity, while a brass addition may generate fumes of 50 percent opacity. A well-designed hood is required over the charge door or rabble door, through which the metal is charged.

Perhaps the most critical operation from the standpoint of air pollution occurs when the furnace is tapped. Nearly continuous emissions of 90 to 100 percent opacity may be expected. Much planning is required to design a hood that completely captures the emissions and yet permits sufficient working room and visibility of the molten metal. Again, the burners should be turned off or throttled as much as possible to reduce the quantity of fumes emitted.

The fluxes used in reverberatory furnaces normally present no air pollution problems. Generally, only nonvolatile fluxes such as borax, soda ash, and iron oxide mill scale are used.

Reverberatory furnace--cylindrical type

Cylindrical-type reverberatory furnaces present all the collection problems of the open-hearth type with the additional complication of furnace rotation. The cylindrical furnace may be rotated up to 90° for charging, slag removing, and metal tapping. With hoods installed in fixed position, the source of emissions may be several feet from the hood, and thus no fumes would be collected. Either a hood attached to the furnace and venting to the control device through flexible ductwork, or an oversized close-fitting hood covering all possible locations of the emission source is required. A close-fitting hood and high indraft velocities are often necessary. For example, an auxiliary hood over the combination charge and slag door of a cylindrical brass furnace was incapable of collecting all emissions, despite an indraft velocity of 1,370 fpm. A similar hood over the pouring spout was also inadequate, despite an indraft velocity of 1,540 fpm. Both hoods were improperly shaped and were located too high above the source for adequate capture.

A cylindrical furnace rotates on its longitudinal axis, and a tight breeching is mandatory at the gas discharge end of the furnace. Adequate indraft velocity must be maintained through the breeching connection to prevent the escape of fumes.

The exhaust system for the cylindrical furnace, as well as for all types of reverberatory furnaces, must be designed to handle the products of combustion at the maximum fuel rate. Any lesser capacity results in a positive pressure within the furnace during periods of maximum firing with resultant emissions from all furnace openings.

Reverberatory furnace--tilting type

The tilting-type furnace differs from the reverberatory furnaces previously discussed in that the exhaust stack is an integral part of the furnace and rotates with the furnace during charging, skimming, and pouring. One type of tilting furnace is charged through the stack, and skimming and pouring are accomplished through a small tap hole in the side of the furnace. Another type has a closeable charge door, and a small port through which the furnace gases escape. These two furnace openings may describe a full 180° of arc during the various phases of a heat.

The wide range of position of the sources makes complete capture of the fumes difficult. One successful system utilizes a canopy hood, with side panels that completely enclose the furnace. Clearance for working around the furnace is provided and a minimum indraft velocity of 125 fpm is required for this opening. This velocity provides complete capture of the emissions unless a cross-draft of 50 to 200 fpm prevails within the furnace room, in which case an estimated 10 percent of the fumes within the furnace hood escape from beneath the hood. This condition is corrected by suspending an asbestos curtain from the windward side of the hood to the floor.

Reverberatory furnace--rotary tilting type

The rotary-tilting-type of furnace not only tilts for charging and pouring but rotates during the melting period to improve heat transfer. Two types are common. One is charged through the burner end and is poured from the exhaust port of the furnace, opposite the burner. The other has a side charge door at the center of the furnace through which charging, slagging, and pouring operations are conducted.

Because of the various movements of this type of furnace, direct connection to the control device is not feasible. The furnace is under positive pressure throughout the heat, and fumes are emitted through all furnace openings.

Hooding a rotary-tilting-type reverberatory furnace for complete capture of fumes is difficult, and complete collection is seldom achieved. These furnaces are undoubtedly the most difficult type of brass furnace to control. To hood them effectively requires a comprehensive design. The major source of emissions occurs at the furnace discharge. Capture of fumes is accomplished by a hood or stack placed approxi-

mately 18 inches from the furnace. This clearance is necessary to allow sufficient room for tilting the furnace for pouring. A minimum indraft velocity of 1,750 fpm is usually required. Although this method controls the emissions during the melting phase, capturing the dense fumes generated during the pour is difficult.

Hooding is sometimes installed at the burner end of a furnace to capture emissions that may escape from openings during melting, or particularly during the time the furnace is tilted to pour. Because both ends of the furnace are open, a venting action is created during the pour, causing fume emissions to be discharged from the elevated end of the furnace. Close hooding is not practicable because the operator must observe the conditions within the furnace through the open ends. An overhead canopy hood is usually installed. Figure 188 illustrates an installation in which a canopy hood is used to capture emissions from one end of the furnace while, at the opposite end, baffles have been extended from around the stack opening to minimize crossdrafts and aid in capturing emissions from the ladle being filled from the furnace.

Additional heavy emissions may be expected during charging, alloying, and slagging. High-overhead canopy hoods are generally used. These overhead hoods are, however, unsatisfactory unless they cover a large area, and a high indraft velocity is provided.
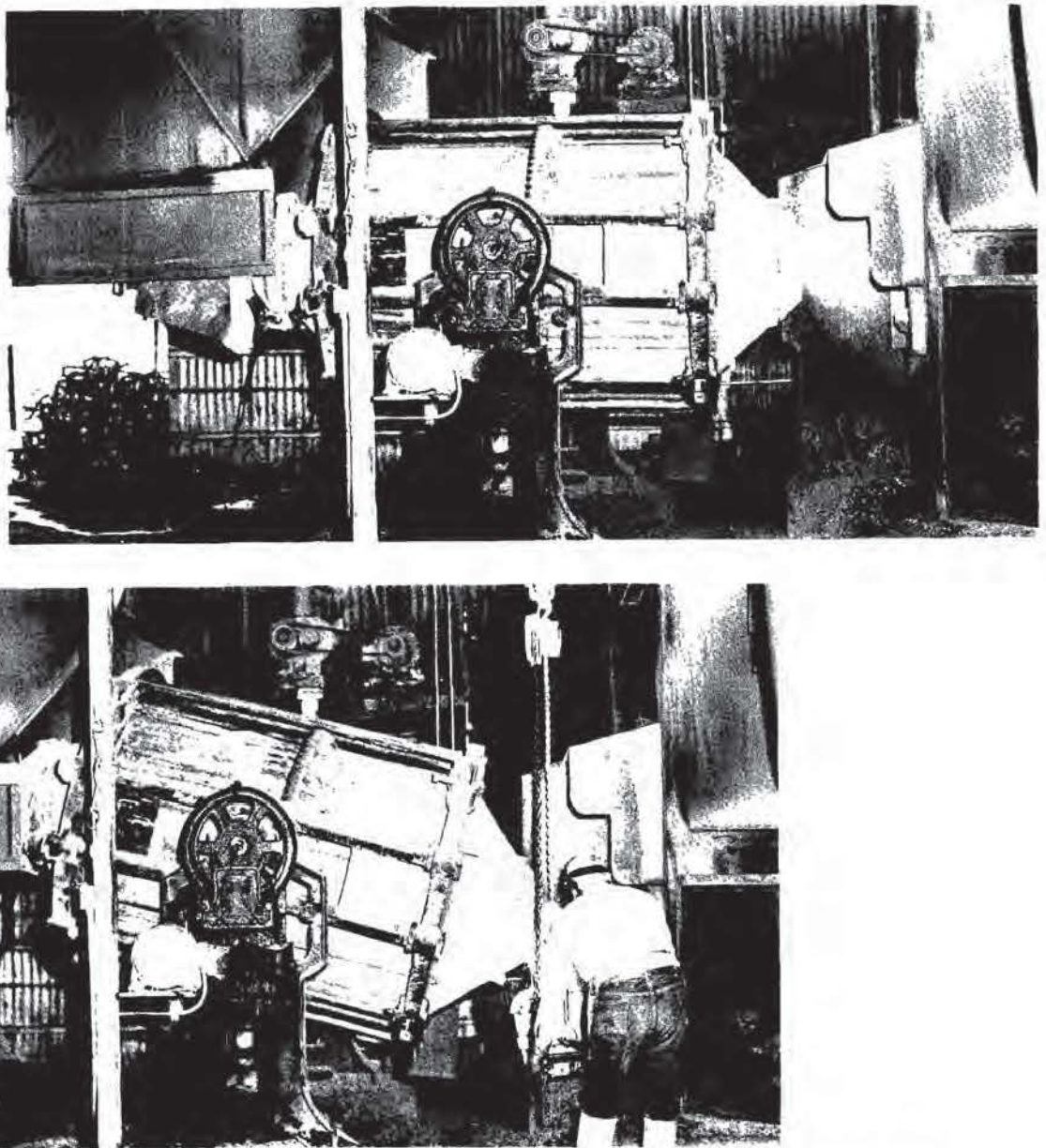

Figure 188. Rotary-tilting-type reverberatory furnace venting to canopy hood and stack vent: (top) Furnace during meltdown, (bottom) furnace during pour (Valley Brass, Inc. El Monte, Calif.).

The need for numerous hoods and large air volumes, with the resultant larger control device, makes the tilting-type open-flame furnace expensive to control. This type of furnace is being gradually replaced by more easily controllable equipment.

The following example illustrates the fundamental design considerations of a side-draft hood for a rotary-tilting-type furnace.

Example 28

Given:

Rotary-tilting-type brass-melting furnace. Fuel input, 17 gal/hr U.S. Grade No. 5 fuel oil. Maximum temperature of products of combustion discharged from furnace, 2,600°F.
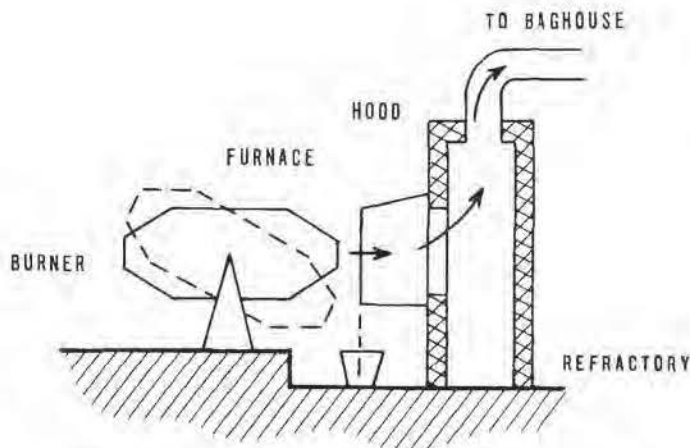
Figure 189. Rotary-tilting-type brass-melting furnace.

Problem:

Determine the design features of a side-draft hood to vent the furnace.

Solution:

1. Volume and weight of products to be vented from furnace:

   With 10% excess air, 1 lb of U.S. Grade No. 5 fuel oil yields 206.6 ft^3 or 15.96 lb of products of combustion. One gallon of fuel oil weighs 8 lb.

$$\text{Vol} = \frac{(17)(8)(206.6)}{60} = 468 \text{ scfm}$$

$$\text{Wt} = \frac{(17)(8)(15.96)}{60} = 36.2 \text{ lb/min}$$

2. Volume of ambient air required to reduce temperature of products of combustion from 2,600° to 250°F:

Baghouse inlet design temperature selected, 250°F. Ambient air temperature assumed to be 100°F.

$$\left\{ \begin{array}{l} \text{Heat gained by} \\ \text{ambient air} \end{array} \right\} = \left\{ \begin{array}{l} \text{Heat lost by products} \\ \text{of combustion} \end{array} \right.$$

$$M_a C_p \Delta t_a = M_{pc} C_p \Delta t_{pc}$$

$$(M_a)(0.25)(250-100) = (36.2)(0.27)(2,600-250)$$

$$37.5 \, M_a = 23,000$$

$$M_a = 613 \text{ lb/min}$$

$$\text{or} \quad \frac{613}{0.071} = 8,640 \text{ cfm at } 100°F$$

3. Total volume of products to be vented through hood:

$$\text{Volume from furnace} = (468)\left(\frac{250 + 460}{60 + 460}\right)$$

$$= 639 \text{ cfm}$$

$$\text{Volume from ambient air} = (8,640)\left(\frac{250 + 460}{100 + 460}\right)$$

$$= 10,950 \text{ cfm}$$

$$\text{Total} = 11,589 \text{ cfm at } 250°F$$

4. Open area of hood: Design for a velocity of 2,000 ft/min. This is adequate to ensure good pickup if the hood geometry is designed properly.

$$\frac{11,589}{2,000} = 5.78 \text{ ft}^2$$

Problem note: Furnace gases should discharge directly into center of hood opening. Positioning of the hood should be such that it picks up emissions from the ladle during the furnace tilt and pour. Sides extending to ground level may be necessary to nullify crossdrafts. When the

furnace is tilted, emissions will escape from the high side or the firing end opening. These may be stopped by blowing a portion of the burner combustion air through the furnace, which forces emissions through the furnace discharge opening. If this is not possible, an auxiliary hood should be installed over the firing end of the furnace.

Crucible-type furnaces

One large-volume foundry, using tilting-type crucible furnaces, installed an exhaust system to control emissions during pouring. The exhaust system vents 14 furnaces to a baghouse. The hooding collects all the fumes during pouring without interfering with the furnace operation in any way. The hood is equipped with a damper that is closed when the furnace is in the normal firing position. A linkage system opens the damper when pouring begins. After the furnace is tilted 40°, the damper is fully opened, remaining there for the rest of the pour. It swings shut automatically when the furnace is returned to the firing position. The ductwork leading from the hood pivots when the furnace is tilted. The entire hood is fixed to the furnace with two bolts, which permit its rapid removal for periodic repairs to the furnace lining and crucible. Since only one furnace is poured at a time and the system operates only during the pour, only 1,500 cfm is required to collect the fumes. Tests show that the amount of particulate matter emitted to the atmosphere with this system is 0.125 pound per hour per furnace (Anonymous, 1950). This contrasts with a loss of over 2 pounds per hour uncontrolled.

Figure 190 shows an installation of a tilting-type brass crucible furnace with a plenum roof-type hood, which captures furnace emissions during the meltdown and ladle emissions during the pour.

Emissions resulting from the pouring of molten metal from a ladle into molds can be controlled by three devices. The first is a fixed pouring station that is hooded so that the emissions from the ladle and molds are captured during the pouring (Figure 191). A second solution, for smaller foundries, is a hood attached to the pouring ladle and vented to the control system through flexible ductwork. One variation places a small baghouse on the crane holding the ladle so that the ladle is vented over the whole pouring floor. Another variation is a stationary baghouse and sufficient flexible ductwork to allow the hood to travel from mold to mold. A third solution employs a hood attached to the bale, a short section of flexible ductwork, and two ducts—one mounted on the bridge crane and one attached to the stationary crane rails. The ducts are interconnected with a transfer box, which is sealed by a continuous loop of rubberized belt. This allows complete freedom
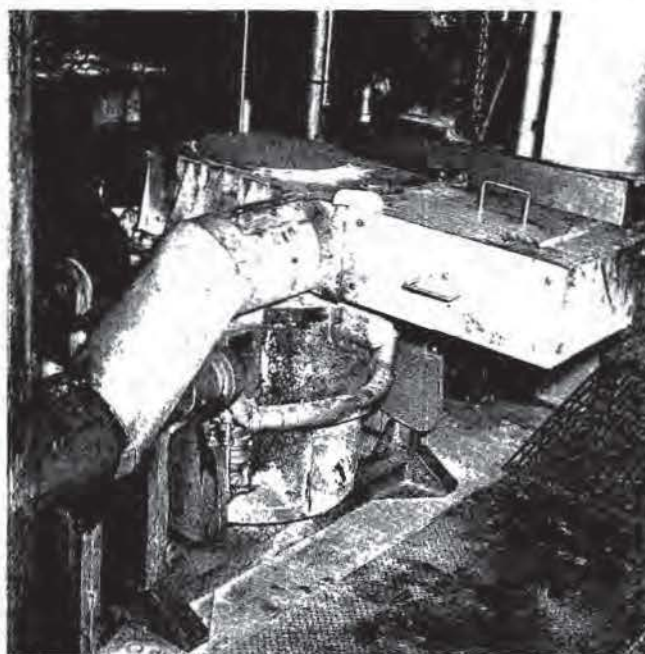

Figure 190. Tilt-type crucible brass furnace with a plenum roof-type hood.
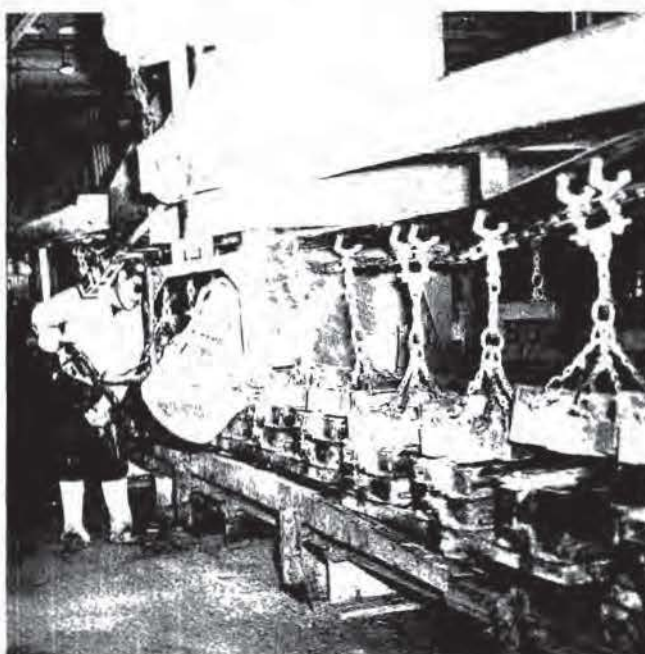

Figure 191. Fixed-mold pouring station with fume mold.

of movement for the ladle within the area served by the overhead crane (Figure 192).

Low-frequency induction furnace

The control of the emissions from an induction furnace is much more expensive and difficult if oily turnings are charged to the furnace. In addition to the fumes common to brass melting,
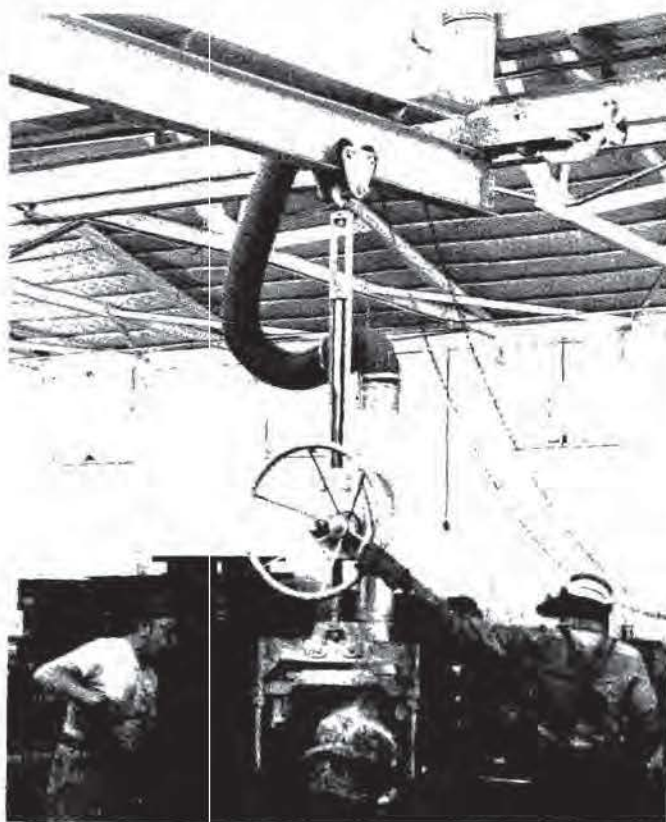
Figure 192. Exhaust system with moving duct and transfer connection venting brass-pouring ladle ("A" Brass Foundry, Vernon, Calif.).

great clouds of No. 5 Ringelmann black smoke are generated when the oily shavings contact the molten heel within the furnace. Adequate hooding enclosing the furnace is, therefore, required, and a large volume of air is necessary to capture the smoke and fumes. Where 900 cfm was sufficient to collect the pouring emissions from an induction furnace using oil-free metal, 10,000 cfm was required throughout the heat for a similarly sized furnace melting turnings with a 3 percent oil content. Figure 193 shows an induction furnace with an adjustable low-canopy hood that can be positioned to cover both meltdown and pouring operations. A baghouse collects the fume.

Another, smaller induction furnace is shown in Figure 194. In addition to capturing furnace emissions during meltdown, the hood captures emissions during the pour into the ladle. Figure 194 also shows the extent of emissions after the ladle is removed from the hood area.

Cupola furnace

An exhaust system to control a cupola must have sufficient capacity to remove the products of combustion, collect the emissions from the metal tap spout, and provide a minimum indraft velocity of 250 fpm through the charge door. In addition,

side curtains may be required around the charge door to shield adverse crosscurrents. A canopy hood is recommended for the metal tap spout. The air requirement for this hood is a function of its size and proximity to the source of emissions.

Air Pollution Control Equipment

Baghouses

Baghouses with tubular filters are used to control the emissions from brass furnaces. This type of collector is available in many useful and effective forms. Wool, cotton, and synthetic filter media effectively separate submicron-sized particulate matter from gases because of the filtering action of the "mat" of particles previously collected.

The gases leaving a reverberatory furnace may be 100° to 200°F hotter than the molten metal and must be cooled before reaching the filter cloth. Direct cooling, by spraying water into the hot combustion gases, is not generally practiced because (1) there is increased corrosion of the ductwork and collection equipment, (2) the vaporized water increases the exhaust gas volume, necessitating a correspondingly larger baghouse, and (3) the temperature of the gases in the baghouse must be kept above the dewpoint to prevent condensation of water on the bags. The exhaust gases may be cooled by dilution with cold air, but this increases the size of the control equipment and the operating costs of the exhaust system.

One cooling system employed consists of a water-jacketed cooler followed by air-cooled radiation-convection columns, as shown in Figure 195. The water-jacketed section reduces the temperature from approximately 2,000° to 900°F. The radiation-convection coolers then reduce the temperature to the degree required to protect the fabric of the filter medium. Figure 196 depicts an actual installation showing the cooling columns and baghouse.

Treated orlon is gradually replacing glass cloth as the most favored high-temperature fabric. Although glass bags withstand higher temperatures, the periodic shaking of the bags gradually breaks the glass fibers and causes higher maintenance costs.

Probably the most critical design factor for a tubular baghouse is the filtering velocity. A filtering velocity of 2.5 fpm is recommended for collecting the fumes from brass furnaces with relatively small concentrations of fume. Larger concentrations of fume require a lower filtering velocity. A higher filtering velocity requires more frequent shaking to maintain a pressure drop through the baghouse within reasonable limits. Excessive bag wear results from frequent
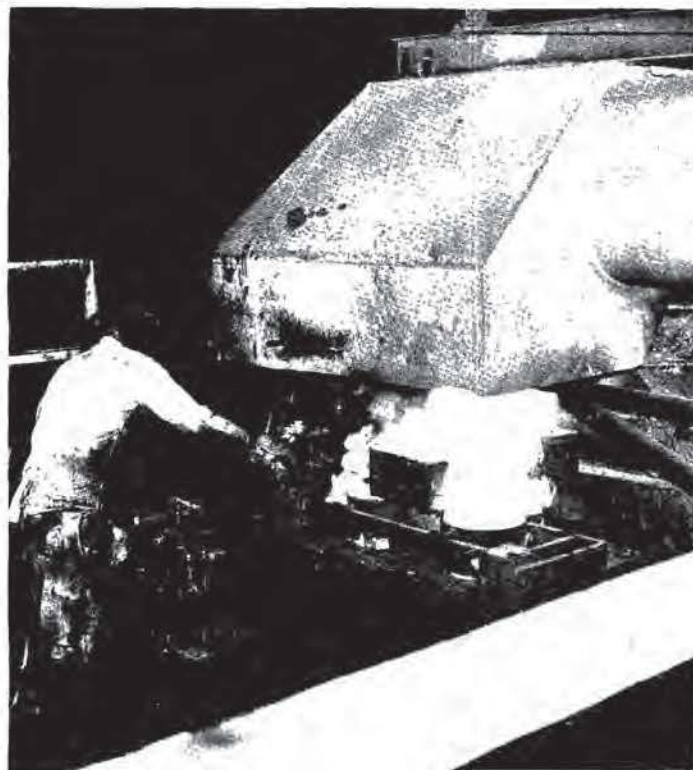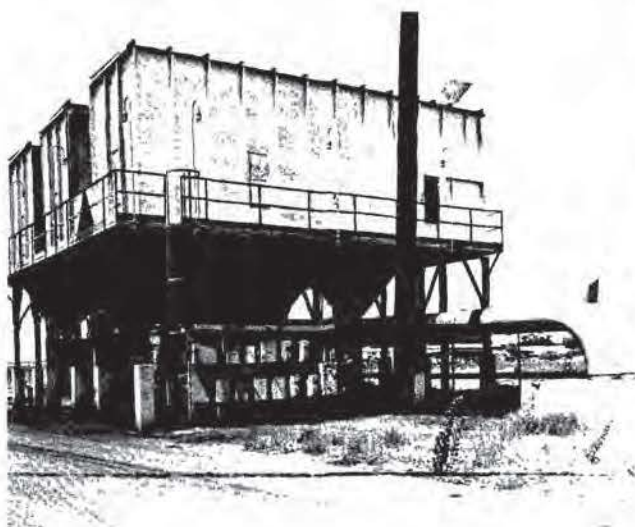
Figure 193. Electric induction tilting-type brass furnace with adjustable canopy hood and baghouse control device (American Brass Company, Paramount, Calif.).

Furnace data

Type, electric induction	Electrical rating, 450 kw
Capacity, 3,000 lb/hr	Metal processed, brass

Control system data

Fan motor rating, 30 hp	Filtering velocity, 1.6 fp
Gas volume, 12,700 cfm	Pressure drop, 1.8 to
Baghouse type, compart-	4 in. WC
mented, tubular	Gas stream cooling, tem-
Filter area, 7,896 ft^2	perature-controlled
Filter medium, orlon	water sprays in duct
Shaking, automatic by	Hood indraft velocity,
compartment	560 ft/min

shaking and higher filtering velocities. A pressure drop of 2 to 5 inches of water column is normal, and high pressure differentials across the bags are to be avoided.

The baghouse should be completely enclosed to protect the bags from inclement weather and water condensation during the night when the equipment is usually idle. The exhaust fan should be placed downstream from the baghouse to prevent blade abrasion. Moreover, problems with fan balance due to material's adhering to the blades will not occur. Furthermore, broken bags are more easily detected when the exhaust system discharges to the atmosphere through one opening.

In Table 81, the results of tests performed on baghouses venting brass furnaces are shown. Note that the melting rate of the induction furnace is over 4 times that of the crucible gas-fired furnaces, yet the baghouse is only one-tenth as large. Larger baghouses are necessary for crucible gas-fired furnaces because of the heat and volume of the products of combustion from the gas burners.

Electrical precipitators

Generally, electrical precipitators are extremely effective collectors for many substances in any size range from 200 mesh (74 μ) to perhaps 0.001 micron, wet or dry, ambient or up to 1,200°F.
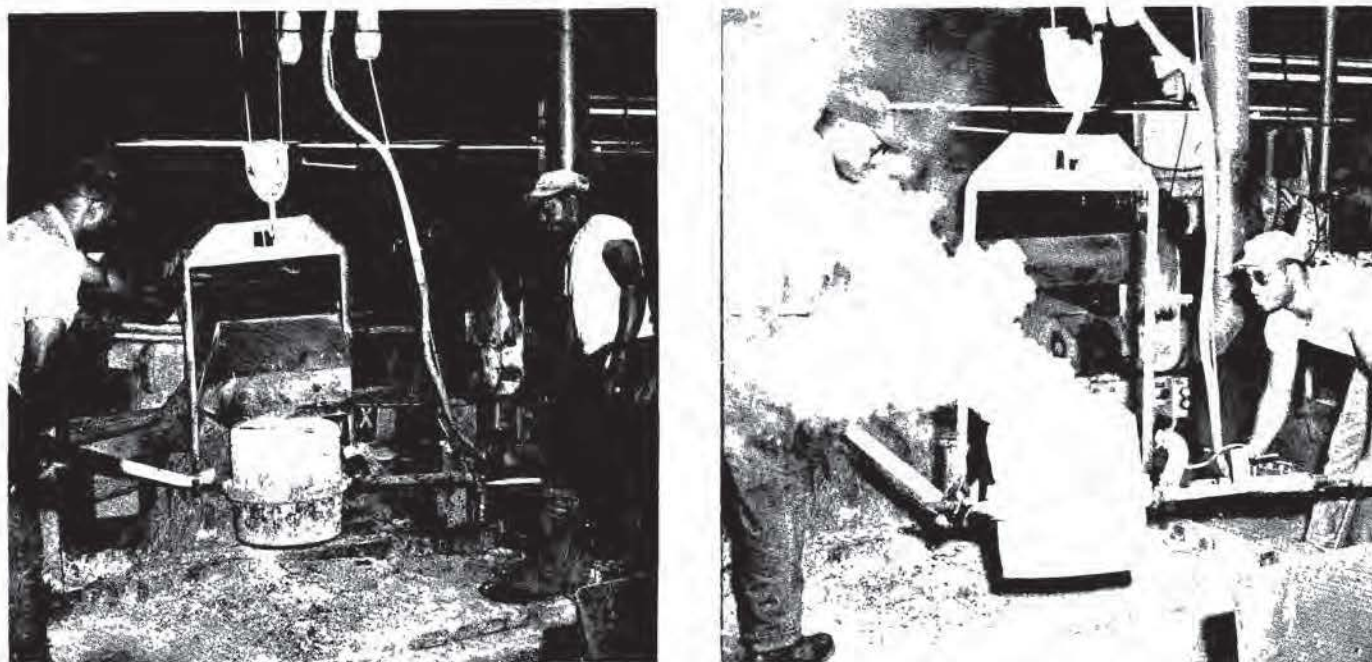
Figure 194.   Electric induction furnace with an extended hood over the pouring area: (left) Hood in place during pouring operations, (right) ladle removed from the hood area (Western Brass Works, Los Angeles, Calif.).
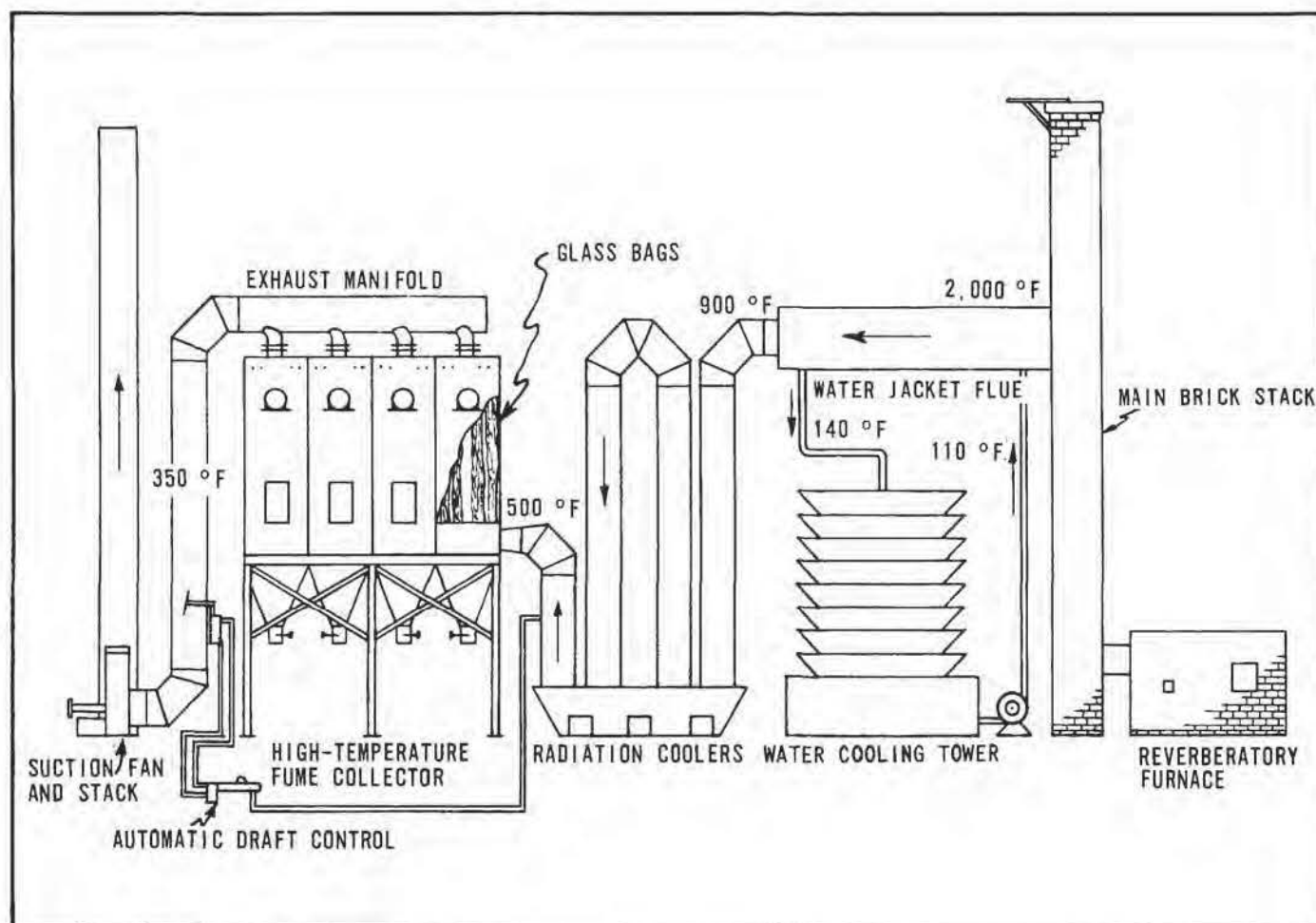

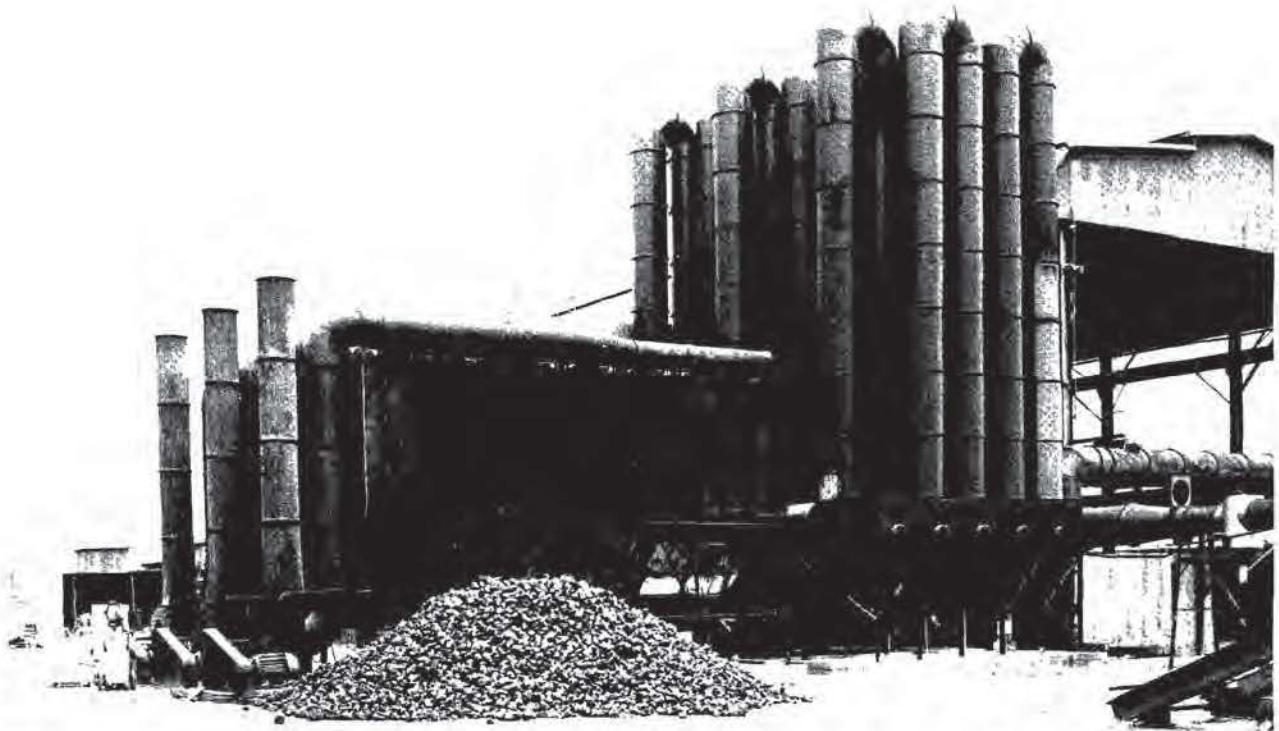Figure 195. Sketch of small baghouse for zinc fume (Allen et al., 1952).

Figure 196. Reverberatory open-hearth furnace whose slagging door and tap hole hoods vent to radiation-convection cooling columns and baghouse (H. Kramer and Company, El Segundo, Calif.).

Furnace data

Type, reverberatory
Capacity, 50 ton

Fuel input, 7,260,000 Btu/hr
Temperature of gas discharge, 2,300°F

Control system data

Three baghouses in parallel serve three reverberatory furnaces and other smaller furnaces.
Fan motor rating, three 50 hp
Maximum gas volume, 54,400 cfm
Baghouse inlet temperature, 220° to 250°F
Filter medium, orlon
Baghouse type, compartmented, tubular

Filter area (3 houses), 27,216 ft^2
Maximum filter ratio, 2:1
Shaking, automatic by compartment

This equipment has not, however, proved entirely satisfactory on lead and zinc fumes. Lead oxide in particular is difficult to collect because of its relatively high resistivity, which can cause a high potential to develop across the dust layer on the collecting surface. This not only reduces the potential across the gas stream but may result in spark discharge with resultant back ionization and re-entrainment of dust. In addition, high-voltage precipitators have not been available in small units suitable for small nonferrous foundry use, and the first cost may, moreover, be prohibitive.

Scrubbers

Dynamic scrubbers or mechanical washers have proved in some applications to be effective from

10 to 1 micron, but in addition to being ineffective in the submicron range, they have the disadvantage of high power consumption and mechanical wear and usually require separation of the metallic fumes and other particulate matter from the circulating water.

A number of dynamic and static scrubbers have been tested on brass furnaces and all have been found unsatisfactory. The scrubbers not only failed to reduce the particulate matter sufficiently, but the opacity of the fumes escaping collection was excessive. The results of several scrubber tests are summarized in Table 82. These scrubbers have been replaced by baghouses.

Table 82. EFFICIENCIES OF WET SCRUBBER CONTROL DEVICES
SERVING BRASS-MELTING FURNACES

Type of scrubber	Water rate, gpm	Flue gas volume, scfm	Particulate matter, gr/scf		Total dust, lb/hr		Efficiency, %
			In	Out	In	Out	
Venturi with wet cyclone	7.6	860	2.71	0.704	19.95	7.04	65
Dynamic wet	20.0	770	0.905	0.367	5.97	3.00	50
Dynamic wet	50.0	1,870	1.76	0.598	28.2	13.2	53

Collectors depending upon centrifugal principles alone are not adapted to brass furnace dust collection because of the low efficiency of these devices on submicron-sized particulate matter. One Los Angeles foundry operated a wet cyclone gas conditioner venting to a wet entrainment separator for recovering partially agglomerated zinc oxide fume. The concentration of particulate matter was relatively small, since tilting crucible furnaces with slag covers were used, and the device was able to reduce the weight of the dust and fumes emitted below the legal limits, but the number of unagglomerated submicron-sized particles escaping collection was sufficient to cause periodic opacity violations. Consequently, this unit has been replaced by a baghouse.

SECONDARY ALUMINUM-MELTING PROCESSES

TYPES OF PROCESS

Secondary aluminum melting is essentially the process of remelting aluminum, but the term encompasses the following additional practices:

1. Fluxing. This term is applied to any process in which materials are added to the melt to aid in removal of gases, oxides, or other impurities, but do not remain in the final product.

2. Alloying. This term is applied to any process in which materials are added to give desired properties to the product and become part of the final product.

3. Degassing. This includes any process used to reduce or eliminate dissolved gases.

4. "Demagging." This includes any process used to reduce the magnesium content of the alloy.

These terms are often used vaguely and overlap to a great extent. For example, degassing and demagging are usually accomplished by means of fluxes. The use of zinc chloride and zinc fluoride fluxes increases the zinc content of aluminum alloys.

Aluminum for secondary melting comes from three main sources:

1. Aluminum pigs. These may be primary metal but may also be secondary aluminum produced by a large secondary smelter to meet standard alloy specifications.

2. Foundry returns. These include gates, risers, runners, sprues, and rejected castings. In foundries producing sand mold castings, foundry returns may amount to 40 to 60 percent of the metal poured.

3. Scrap. This category includes aluminum contaminated with oil, grease, paint, rubber, plastics, and other metals such as iron, magnesium, zinc, and brass.

The melting of clean aluminum pigs and foundry returns without the use of fluxes does not result in the discharge of significant quantities of air contaminants. The melting of aluminum scrap, however, frequently requires air pollution control equipment to prevent the discharge of excessive air contaminants.

Crucible Furnaces

For melting small quantities of aluminum, up to 1,000 pounds, crucible or pot-type furnaces are used extensively. Almost all crucibles are made of silicon carbide or similar refractory material. Small crucibles are lifted out of the furnace and used as ladles to pour into molds. The larger crucibles are usually used with tilting-type furnaces. For die casting, molten metal is ladled out with a small hand ladle or it can be fed automatically to the die-casting machine.

Reverberatory Furnaces

The reverberatory furnace is commonly used for medium- and large-capacity heats. Small reverberatory furnaces up to approximately 3,000 pounds' capacity may be of the tilting type. Sometimes a double-hearth construction is employed in furnaces of 1,000 to 3,000 pounds' holding capacity. This permits melting to take place in one hearth, the second hearth serving only to hold the molten metal at the appropriate temperature. Advocates of this design stress that it reduces or eliminates the tendency of the metal to absorb gas. The contention is that porosity results from hydrogen gas, which is liberated from moisture trapped below the surface of molten aluminum. The use of a double hearth permits moisture to be driven off before the metal melts and runs to the holding hearth. Sometimes the melting hearth is also used as a sweat furnace to separate the aluminum from contaminants such as brass and steel. The use of double-hearth furnaces for the larger capacity heats is not common.

A charging well is frequently used on aluminum reverberatory furnaces. Figure 197 shows a 20-ton reverberatory furnace with a charging well. The well permits chips and other small aluminum scrap to be introduced and immersed below the liquid level. Chips and small scrap have an unusually high surface area-to-volume relationship, and oxidation must be minimized. Large quantities of flux are also added and stirred in to dissolve the oxide coating and aid in the removal of dirt and other impurities. The flux causes the oxides and other impurities to rise to the surface in the form of a dross that can be skimmed off easily.

Reverberatory furnaces of 20- to 50-ton holding capacity are common. Usually one heat is produced in a 24-hour period; however, the time per heat in different shops varies from 4 hours to as much as 72 hours. This type of furnace is commonly used to melt a variety of scrap. The materials charged, method of charging, size and design of the furnace, heat input, and fluxing, refining, and alloying procedures all have some influence on the time required to complete a heat. After the charge is completely melted, alloying ingredients are added to adjust the composition to required specifications. Large quantities of fluxes are added when scrap of small size and low grade is melted. The flux in some cases may amount to as much as 30 percent of the weight of scrap charged.

Fuel-Fired Furnaces

Both gas- and oil-fired furnaces are common, though gas-fired furnaces are usually preferred. Frequently, combination burners are used so that gas may be burned when available, with oil substituted during periods of gas curtailment.

Fuel-fired furnaces used for aluminum melting are extremely inefficient. Approximately 50 percent of the gross heating value in the fuel is unavailable in the products of combustion. Radiation and convection losses are high since little or no insulation is used. Many small crucible furnaces probably do not achieve more than 5 percent overall efficiency and some may not exceed 2 to 3 percent (Anderson, 1925). At the other extreme a properly designed and operated furnace may be able to use as much as 20 percent of the gross heat in the fuel. Most furnaces can be assumed to operate with efficiencies of 5 to 15 percent. This may become an important factor when air pollution control equipment must be provided to handle the products of combustion. Fortunately, this is seldom necessary. Controls, if provided, are usually required only during the degassing or demagging operations when the burners are off. Another possibility is to add fluxes and scrap only to a charging well that is vented to control equipment.

Electrically Heated Furnaces

Electric induction furnaces are becoming increasingly common for both melting and holding aluminum in spite of higher installation and operating costs. Some of the advantages they offer over other furnaces are higher efficiency, closer temperature control, no contaminants from products of combustion, less oxidation, and improved homogeneity of metal. Electric resistance heating is sometimes used for holding but rarely for melting furnaces. Most electric furnaces for aluminum melting are relatively small though some holding furnaces have capacities up to about 15 tons.

Charging Practices

Small crucible furnaces are usually charged by hand with pigs and foundry returns. Many reverberatory furnaces are also charged with the same type of materials, but mechanical means are used because of the larger quantity of materials involved.

When chips and light scrap are melted, it is a common practice to melt some heavier scrap or pigs first to form a molten "heel." The light scrap is then added and immediately immersed below the surface of the molten metal so that further oxidation is prevented. The heel may consist of 5,000 to 20,000 pounds, depending upon the size of the furnace.
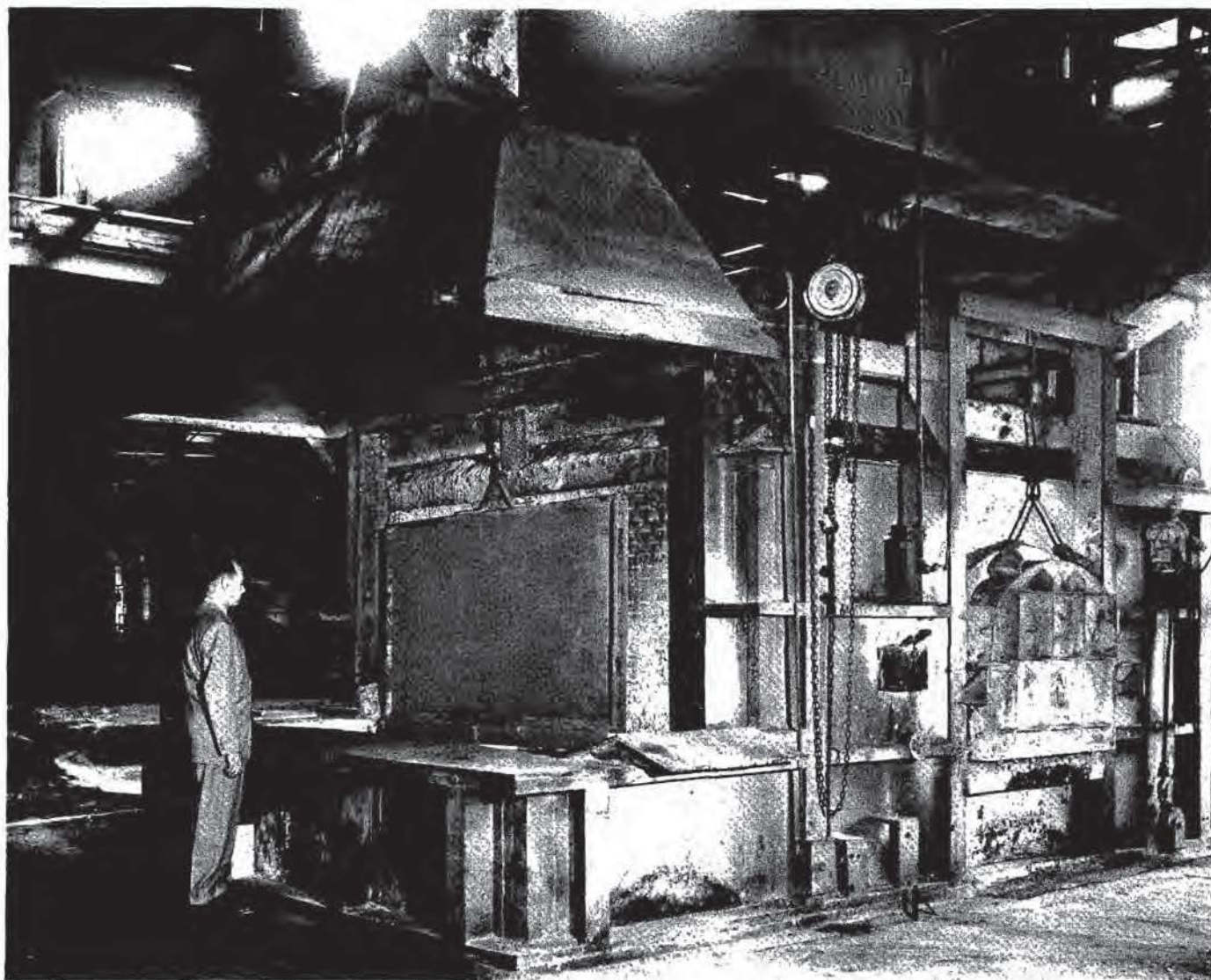
Figure 197. A 20-ton aluminum-melting reverberatory furnace with charging well hood (Aaron,Ferrer & Sons, Inc.,,Los Angeles, Calif.).

Pouring Practices

Tilting-type crucible furnaces are used when the crucible is too large to be handled easily. These furnaces are poured into smaller capacity ladles for transfer to the molds. Larger reverberatory furnaces are either tapped from a tap hole or siphoned into a ladle. Ladles vary up to 3 or 4 tons capacity in some cases. Sometimes the ladles are equipped with covers with electric resistance heaters to prevent loss of temperature when the ladle is not to be poured immediately or when the pouring requires too long a time. Pouring molten aluminum does not usually result in the discharge of air contaminants in significant quantities.

Fluxing

The objectives of fluxing generally fall into four main categories:

1. Cover fluxes. These fluxes are used to cover the surface of the metal to prevent further oxidation and are usually liquid at the melting point of aluminum. Some of these are also effective in preventing gas absorption.

2. Solvent fluxes. These fluxes generally cause the impurities and oxides to float on top of the melt in the form of a dross that can be skimmed off easily.

3. Degassing fluxes. These fluxes are used to
    purge the melt of dissolved gases. The dis-
    solved gas is assumed to be hydrogen, but
    other gases are also highly soluble in alumi-
    num. The solubility of gases in molten alu-
    minum increases with temperature. The gas-
    es most soluble in molten aluminum, in de-
    creasing order of solubility, are hydrogen,
    methane, carbon dioxide, sulfur dioxide, oxy-
    gen, air, and carbon monoxide. The solu-
    bility of hydrogen is 6 or 7 times as great as
    that of methane and over 10 times that of car-
    bon dioxide. Elimination of hydrogen gas in
    aluminum is a major problem.

4. Magnesium-reducing fluxes. These fluxes
    are used to reduce the magnesium content
    of the alloy (known as demagging). During
    World War II it became necessary to recov-
    er large quantities of aluminum scrap, much
    of which had a magnesium content too high
    for the intended use. It was found that the
    magnesium could be selectively removed by
    the use of appropriate fluxes.

The quantity and type of fluxing depend upon the
the type of furnace, the materials being melted,
and the specifications of the final product. A few
operators melting only pigs and returns find flux-
ing unnecessary. At the other extreme are large
secondary smelters that process very low-grade
scrap and sometimes use fluxes amounting to as
much as one-third of the weight of the aluminum
scrap charged. About 10 percent by weight is an
average figure for the amount of flux used for
medium- to low-grade scrap.

Fluxes for degassing or demagging may be either
solids or gases. The gaseous types are usually
preferred because they are easier to use, and the
rate of application is simpler to control. Some of
these, for example chlorine, may be used for
either degassing or demagging, depending upon the
metal temperature. In general, any flux that is
effective in removing magnesium also removes
gas inclusions.

Cover fluxes

Cover fluxes are used to protect the metal from
contact with air and thereby prevent oxidation.
Most of these fluxes use sodium chloride as one
of the ingredients (Anderson, 1931). Various
proportions of sodium chloride are frequently
used with calcium chloride and calcium fluoride.
Sometimes cryolite or cryolite with aluminum
fluoride is added to dissolve oxides. Borax has
also been used alone and in combination with so-
dium chloride.

Solvent fluxes

Solvent fluxes usually form a gas or vapor at the
temperature of the melt. Their action is largely
physical. The resulting agitation causes the ox-
ides and dirt to rise to the top of the molten metal
where they can be skimmed off. Included in this
group are aluminum chloride, ammonium chlo-
ride, and zinc chloride. Zinc chloride increases
the zinc content of the alloy probably according
to the equation

$$3 \, Zn Cl_2 \; + \; 2 \, Al \longrightarrow 3 \, Zn \; + \; 2 \, AlCl_3 \quad (100)$$
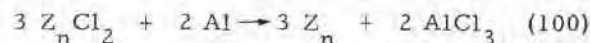
Aluminum chloride, which is formed in this re-
action, is a vapor at temperatures above $352°F$.
It bubbles out of the melt, forming a dense white
fume as it condenses in the atmosphere.

So-called chemical fluxes are solvents for alu-
minum oxide. Cryolite, other fluorides, or borax
is used for this purpose. Part of the action of
the fluorides is thought to be due to the libera-
tion of fluorine, which attacks silicates and dirt.
Some chlorides are also used extensively, but their
action is not understood.

Degassing fluxes

There are many methods of removing dissolved
gas from molten aluminum, some of which do not
require the addition of a flux. Among the non-
flux methods are the use of vibration, high vac-
uum, and solidification with remelting. None is
as effective as the use of an active agent such as
chlorine gas. Helium, argon, and nitrogen gases
have also been used successfully. Solid materials
that have been used include many metallic chlo-
rides. Some think that their action is physical
rather than chemical and that one gas is as good
as another. For this reason, nitrogen has been
used extensively. Nitrogen is not toxic, and vir-
tually no visible air contaminants are released
when it is used. In addition, it does not coarsen
the grain or remove sodium or magnesium from
the melt. The main objection to the use of nitro-
gen is that commercial nitrogen is usually con-
taminated with oxygen and water vapor (Eastwood,
1946).

Magnesium-reducing fluxes

The use of fluxes to reduce the magnesium con-
tent of aluminum alloys is a relatively new pro-
cedure. Certain fluxes have long been known to
tend to reduce the percent of magnesium in the
alloy, but this process did not become common-
place until the advent of World War II. Several
fluxes may be used for this purpose. Aluminum

fluoride and chlorine gas are perhaps the most commonly used. The temperature of the melt must be significantly greater in demagging than in degassing, usually between 1,400° and 1,500°F.

As much as 1 ton of aluminum fluoride is commonly used in reverberatory furnaces of 40- to 50-ton capacity. The aluminum fluoride is usually added to the molten metal with smaller quantities of other fluxes such as sodium chloride, potassium chloride, and cryolite, and the entire melt is stirred vigorously. Magnesium fluoride is formed, which can then be skimmed off. Large quantities of air contaminants are discharged from this process.

Magnesium reduction with chlorine

Chlorine gas used for demagging is easier to regulate than fluxes used for that purpose. Extra precautions must be taken because of the high toxicity of this material. The chlorine is sent under pressure through carbon tubes or lances to the bottom of the melt and permitted to bubble up through the molten aluminum. Figure 198 (left) shows a ladle of aluminum before the lances are lowered into the metal; Figure 198 (right) shows the hood in position.

Recently, aluminum reverberatory furnaces have been provided with chlorination chambers. A typical chamber is approximately 4 feet wide and 10 feet long, and is located alongside the furnace. An archway beneath the molten metal level in the common wall between the furnace and the chamber permits the flow of metal between the furnace and the chamber. Chlorine under pressure is fed through carbon lances to the bottom of the melt in the chlorination chamber. Use of this chamber permits chlorination during the latter part of the melting cycle and has the added advantage of isolating the contaminant gases and entrained emissions, formed by the demagging process, from the combustion products of the furnace.

THE AIR POLLUTION PROBLEM

Frequently, a large part of the material charged to a reverberatory furnace is low-grade scrap and chips. Paint, dirt, oil, grease, and other contaminants from this scrap cause large quantities of smoke and fumes to be discharged. Even if the scrap is clean, large surface-to-volume ratios require the use of more fluxes, which can cause serious air pollution problems.

In a study of the extent of visible emissions discharged from degassing aluminum with chlorine
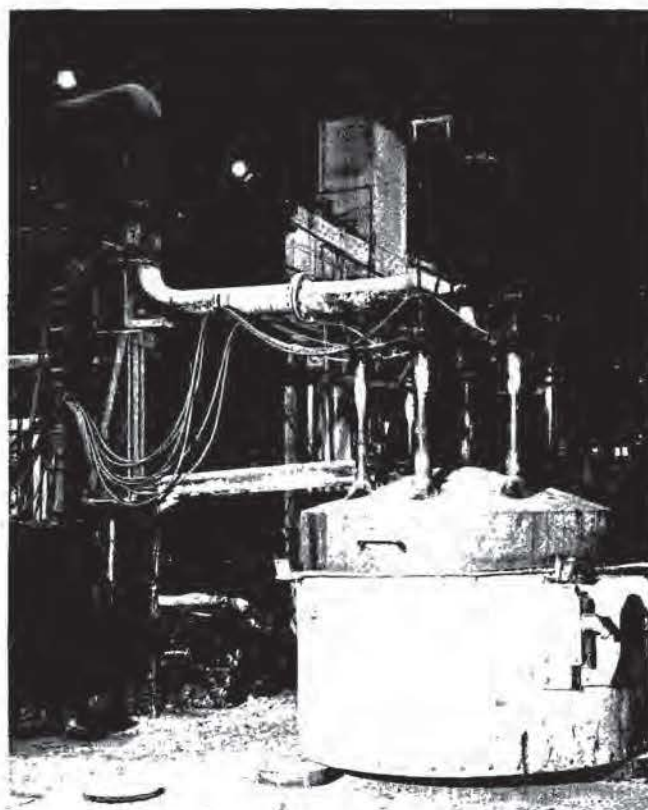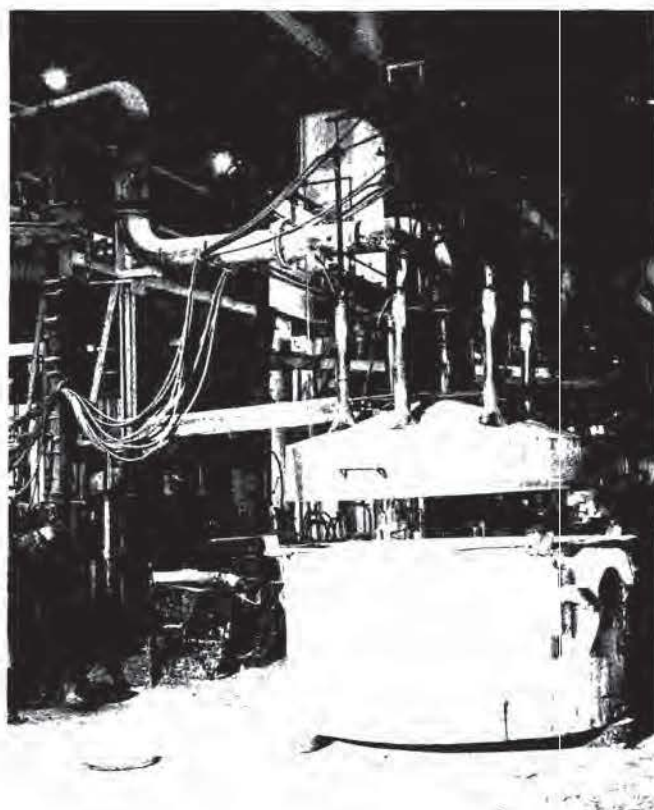

Figure 198. Ladle of molten aluminum with (left) lances in the raised position, and (right) hood in place and lances lowered into aluminum.

gas, the major parameters were found to be metal temperature, chlorine flow rate, and magnesium content of the alloy. Other factors affecting the emissions to a lesser degree are the depth at which the chlorine is released and the thickness and composition of the dross on the metal surface. Other factors remaining constant, the opacity of the emissions at any time is an inverse function of the percent magnesium in the metal at that time.

When the magnesium content is reduced, either by combining with chlorine to form magnesium chloride ($MgCl_2$) or by using an alloy containing less magnesium, a greater fraction of the chlorine combines with the aluminum to form aluminum chloride ($AlCl_3$). The magnesium chloride melts at about 1,312°F, so that it is a liquid or solid at normal temperatures for this operation (about 1,300° to 1,350°F) and thus does not contribute significantly to the emissions. A very small amount may sometimes be released into the atmosphere as a result of mechanical entrainment. The aluminum chloride, on the other hand, sublimes at about 352°F, so that it is a vapor at the temperature of molten aluminum. As the vapors cool in the atmosphere, submicron fumes are formed, which have very great opacity in proportion to the weight of material involved.

Chlorine has a much greater affinity for magnesium than it has for aluminum. This is shown by the fact that alloys containing more than about 0.5 percent magnesium (and 90 to 97 percent aluminum) usually produce only a moderate quantity of fume in degassing with chlorine, while alloys with more than about 0.75 percent magnesium do not usually produce a significant quantity of fume.

In alloys with greater magnesium content, not only is less aluminum chloride formed, but also a thick layer of dross (largely magnesium chloride) is built up on the surface, which further suppresses the emission of fumes. Aluminum chloride also reacts with magnesium to form magnesium chloride and aluminum. The dross increases the opportunities for this latter reaction.

When chlorine is used for demagging, it is added so rapidly that large quantities of both aluminum chloride and magnesium chloride are formed, the molten bath is vigorously agitated, and not all of the chlorine reacts with the metals. As a result, a large quantity of aluminum chloride is discharged along with chlorine gas and some entrained magnesium chloride. The aluminum chloride is extremely hygroscopic and absorbs moisture from the air, with which it reacts to form hydrogen chloride. These air contaminants are toxic, corrosive, and irritating.

Particle Size of Fumes From Fluxing

One study (McCabe, 1952) found that the major constituent in the fume from salt-cryolite fluxing in a furnace was sodium chloride with considerable smaller quantities of compounds of aluminum and magnesium. Electron photomicrographs of thermal precipitator samples indicated that the particles of fume were all under 2 microns, most of them being 0.1 micron. The fumes were somewhat corrosive when dry and, when collected wet, formed a highly corrosive sludge that tended to set up and harden if allowed to stand for any appreciable time. Another study made of the fume from chlorinating aluminum to degas revealed that 100 percent of the fume was smaller than 2 microns and 90 to 95 percent smaller than 1 micron. Mean particle size appeared under a microscope to be about 0.7 micron.

HOODING AND VENTILATION REQUIREMENTS

When no charging well is provided, or when fluxing is done inside the furnace, or when dirty scrap is charged directly into the furnace, then venting the furnace may be necessary. In some cases, the products of combustion must be vented to the air pollution control equipment. The volume to be vented to the collector, and the determination of temperature may be found similarly to metallurgical furnace calculation procedures described elsewhere in this manual.

A canopy hood (as previously shown in Figure 197) is usually used for capturing the emissions from the charging well of an aluminum reverberatory furnace. Calculation of the quantity of air required can be accomplished as shown in the following example.

Example 29

Given:

Metal surface, 2 ft 3 in. x 11 ft 3 in.
Temperature of molten metal, 1,350°F.
Hood opening dimensions, 3 ft 9 in. x 13 ft 9 in.
Height of hood face above metal surface, 2 ft 6 in.
Ambient air temperature, 80°F.

Problem:

Determine the volume of air that must be vented from a low-canopy hood over the charging well of an aluminum-melting reverberatory furnace to ensure complete capture of the air contaminants.

Solution:

As discussed in Chapter 3, the following equation gives the total ventilation rate for low-canopy hoods:

$$q = 5.4 (A)(m)^{1/3} (\Delta t)^{5/12}$$

where

q = total ventilation rate required, cfm

A = area of the hood face, ft^2

m = the width of the hot metal surface at the charging well, ft

Δt = the difference in temperature between the hot surface and the ambient air, °F.

$$q = (5.4)(3.75)(13.75)(2.25)^{1/3} (1,350-80)^{5/12}$$

$$= 7,170 \text{ cfm}$$

Problem note: The volume calculated here is the minimum ventilation required just to accommodate the rising column of air due to the thermal drive. An additional allowance must be made to take care of drafts. If volatile fluxes are used, the volume of fumes generated must also be accommodated. In most cases an allowance of about 25 percent additional volume is adequate to ensure complete pickup. The exhaust system should therefore be designed to vent about 9,000 cfm.

Although the gases vented from the charging well are hot, sufficient air is drawn into the hood to preclude any danger that the hot gas will damage the exhaust system. The temperature of the mixed gas stream is calculated in example 30.

Example 30

Given:

The furnace with charging well and canopy hood venting 9,000 cfm as shown in Example 29.

Problem:

Determine the temperature of the air entering the hood.

Solution:

1. Determine the heat transferred from the hot metal surface to the air by natural convection:

From Chapter 3, $H' = \dfrac{h_c A_s \Delta t}{60}$

where

H' = heat transferred from hot metal surface to the air by natural convection, Btu/min

h_c = coefficient of heat transfer from horizontal plates by natural convection, $Btu/hr/ft^2/°F$

A_s = area of hot metal surface, ft^2

Δt = temperature difference between hot metal surface and ambient air, °F.

By using $h_c = 0.38 (\Delta t)^{0.25}$ and substituting this quantity into the equation,

$$H' = \frac{0.38 (A_s)(\Delta t)^{1.25}}{60}$$

$$H' = \frac{(0.38)(2.25)(11.25)(1,350-80)^{1.25}}{60}$$

$$= 1,210 \text{ Btu/min}$$

2. Solve for temperature of the air entering the hood (assume specific volume of air = 13.8 ft^3/lb):

$$q = W c_p \Delta t$$

where c_p = specific heat of air at constant pressure.

$$\Delta t = \frac{(1,210)(13.8)}{(9,000)(0.24)} = 7.7°F$$

Temperature of air entering the hood = 80 + 7.7 = 87.7°F.

The actual temperature of the air entering the hood will be slightly higher than the value calculated here, owing to radiation from the molten metal surface, and radiation and convection from the hood and the furnace. In some cases, when the burners are operated at maximum capacity, there may be a positive pressure in the furnace. If the design of the furnace permits some of the products of combustion to be vented into the hood, the actual temperature may be substantially higher than shown here. This situation would also require venting a greater volume to ensure capturing the emissions.

AIR POLLUTION CONTROL EQUIPMENT

The emissions from aluminum fluxing may consist of hydrogen fluoride, hydrogen chloride, and chlorine in a gaseous state, and aluminum chloride, magnesium chloride, aluminum fluoride, magnesium fluoride, aluminum oxide, magnesium oxide, zinc chloride, zinc oxide, calcium fluoride, calcium chloride, and sodium chloride in the solid state. Not all will be present at one time, and many other, minor contaminants may be emitted in a specific case. Because of the widely divergent properties of these various air contaminants, the problem of control is complicated.

Some type of scrubber is required to remove the soluble gaseous fraction of the effluent, and either a baghouse or an electrical precipitator is needed to control the solids. In order to obtain adequate collection efficiency, the use of high-efficiency scrubbers, with a caustic solution as the scrubbing medium, has been found necessary. This is illustrated in Table 83, which shows typical test data on collection efficiency for both ordinary and high-efficiency scrubbers.

Table 83. SCRUBBER COLLECTION EFFICIENCY FOR EMISSIONS FROM CHLORINATING ALUMINUM

	Scrubber collection efficiencies, %[a]			
	Slot scrubber		Packed-column scrubber	
Contaminants	Water	10% caustic solution	Water	10% caustic solution
HCL	90 to 95	95 to 99	95 to 98	99 to 100
CL$_2$	30 to 50	50 to 60	75 to 85	90 to 95
Particulates	30 to 50	50 to 60	70 to 80	80 to 90

[a] Collection efficiency depends mainly upon scrubbing ratio (gal per 1,000 ft^3), velocity of gas in scrubber, and contact time and to a lesser extent on other aspects of the design. These values are typical efficiencies obtained by actual tests but do not reflect the entire range of results.

Table 84 summarizes the results of a series of 200 tests made of control efficiencies of nine devices by a major producer of aluminum (Jenny, 1951). These results represent the average range of efficiencies for a number of tests but are not necessarily the maximum or minimum values obtained. In spite of the high efficiencies obtained with some of these devices, reducing the emissions sufficiently to eliminate a visible plume was very difficult. For the dry ultrasonic unit, the opacity of the emissions exceeded 40 percent when the outlet grain loading was greater than 0.25 grain per cubic foot. The efficiency of this unit varied widely with the inlet grain loading and

Table 84. AVERAGE COLLECTION EFFICIENCY OBTAINED BY VARIOUS DEVICES ON EMISSIONS FROM CHLORINATING ALUMINUM (Jenny, 1951)

Type of device	Efficiency, %
Horizontal multipass wet cyclone	65 to 75
Single-pass wet dynamic collector	70 to 80
Packed-column water scrubber with limestone packing	75 to 85
Ultrasonic agglomerator followed by a multitube dry cyclone	85 to 98
Electrical precipitator	90 to 99

retention time, the efficiency increasing with increasing values of either or both of these variables. Other tests by the same company on collectors of a wet type revealed that the opacity exceeded 40 percent periodically, even when the average grain loading at the vent was as low as 0.002 grain per cubic foot.

Figures 198, 199, and 200 show parts of a single installation of air pollution control equipment for the control of emissions from chlorinating aluminum. One of the three stations where chlorinating is performed is shown in Figure 198. Note that the hooding closely encloses the source so that a minimum volume of air is required to attain 100 percent pickup of air contaminants. The fumes are scrubbed in the packed-column scrubbers shown in Figure 199. This system was designed to use two of the three scrubbers in parallel, with the third as a standby. The scrubbing medium is a 10 percent caustic solution. After the scrubbing, the effluent is vented to a five-compartment baghouse with a fully automatic shaking mechanism to remove residual particulate matter. The baghouse contains a total of 300 orlon bags with a net filtering area of 12,000 square feet. In addition to the fumes from chlorine fluxing, which are vented through the scrubbers, two aluminum dross-processing barrels (Figure 200) are vented directly to the baghouse. The total volume handled by the baghouse is about 30,000 cfm, of which
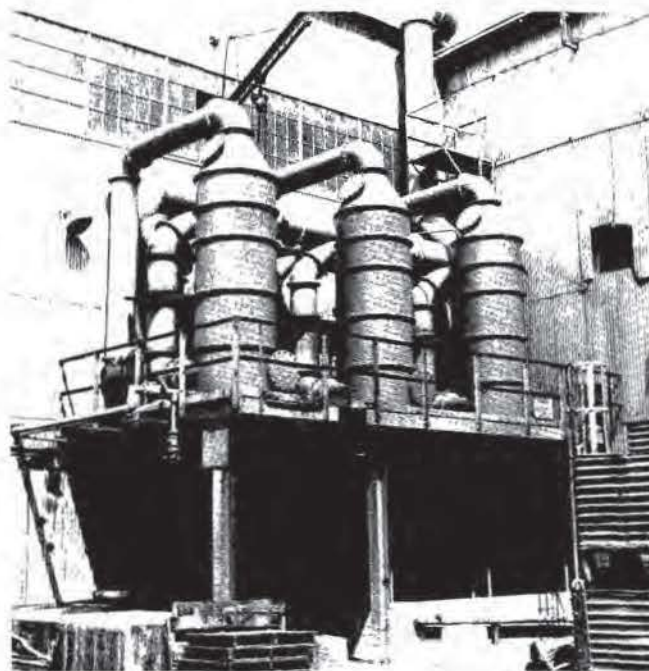

Figure 199. High-efficiency packed-column water scrubbers used with a baghouse for control of emissions from chlorine fluxing and dross processing.

approximately 6,000 cfm is from the three chlorine fluxing stations and the balance from the two dross barrel hoods. The beneficial effect of the bag precoating provided by the aluminum oxide dust vented from the dross-processing barrels permits a much higher filtering velocity than would be advisable if only the fluxing stations were being served by the baghouse.

Tests of the scrubber performance have shown that virtually all the hydrogen chloride and more than 90 percent of the chlorine are removed by the caustic scrubbing solution. Since the efficiency of aluminum chloride removal averages in excess of 80 percent, the loading of hygroscopic and corrosive materials to the baghouse is relatively light. The aluminum oxide dust from the dross barrels acts as a filter cake, which improves the collection efficiency of the aluminum

chloride fume while simultaneously reducing or eliminating the difficulties usually associated with collecting hygroscopic materials. All exposed metal parts are coated with polyvinyl chloride or other appropriate protective coatings. The first year of operation indicates that no serious operational or maintenance problems will develop. This installation replaced an electrical precipitator that was found extremely difficult and expensive to maintain because of corrosion.

An electrical precipitator that has been used successfully to control the emissions from fluxing aluminum is illustrated in Figure 201. At present the trend in control equipment for aluminum-fluxing emissions appears to be away from electrical precipitators and toward the scrubber-baghouse combination.
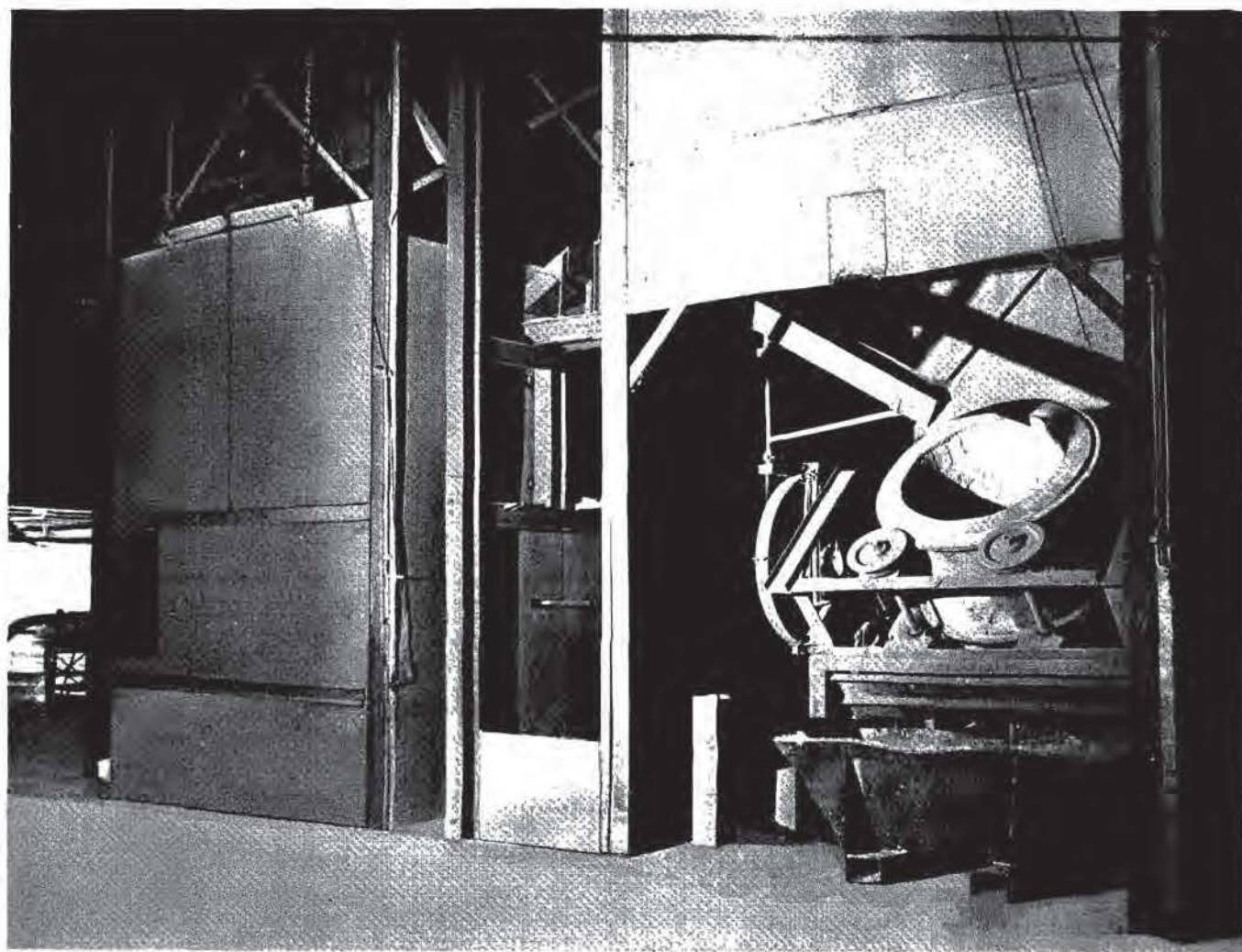

Figure 200. Two aluminum dross-processing stations, one shown with hood door raised.
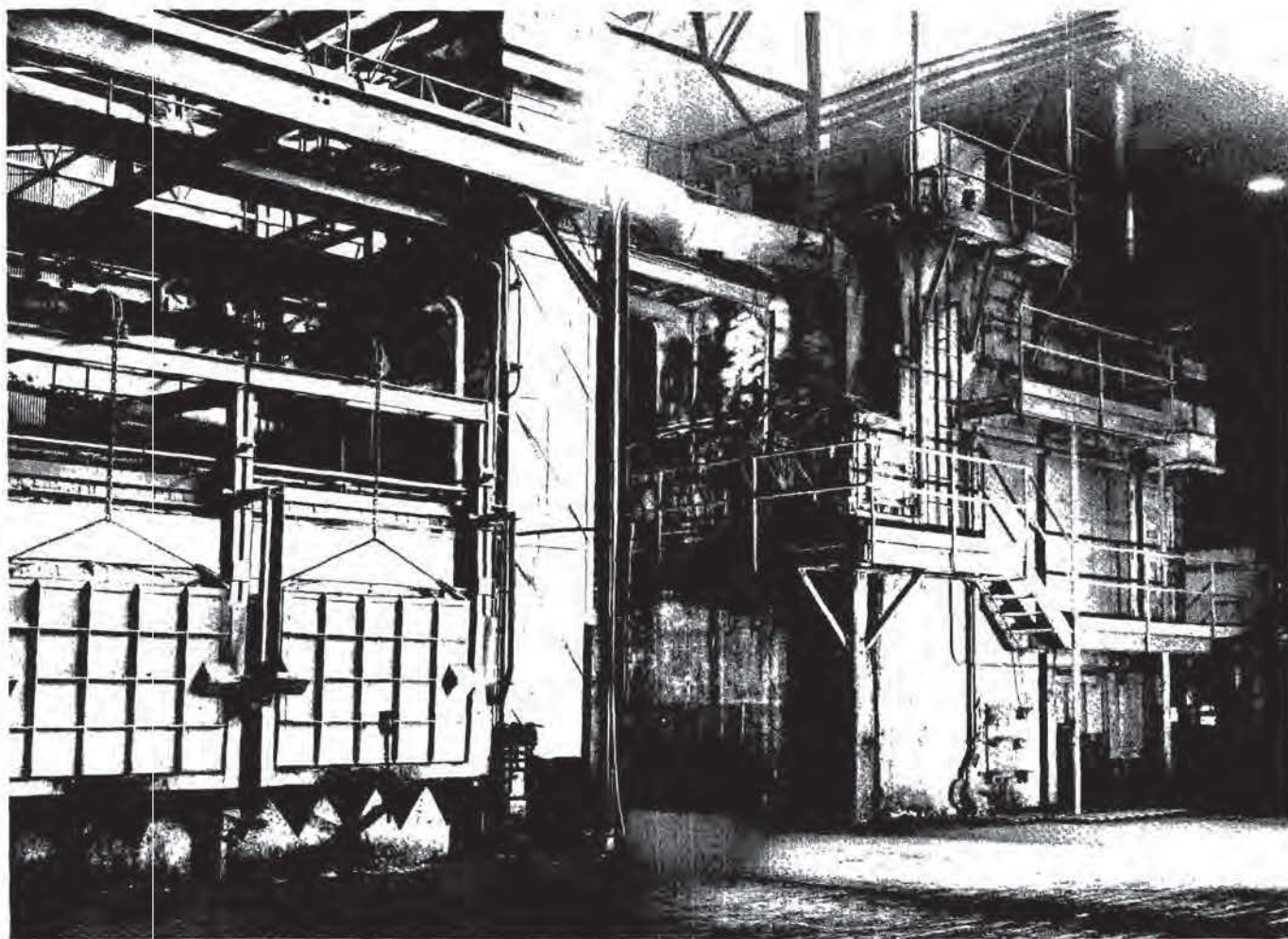
Figure 201. Concrete shell-type electrical precipitator used for controlling emissions from fluoride fluxing aluminum metal. The reverberatory furnace is shown in the left portion of the photograph (Apex Smelting Co., Long Beach, Calif.).

As mentioned earlier in this section, the demagging operation can be done in a separate chlorination chamber. Exhaust volumes required to control the emissions are much lower when a chlorination chamber is used than when demagging is done in the main chamber of the furnace. The chlorination chamber is virtually sealed from the atmosphere, the only exception being the cracks in the refractory. An exhaust system capable of providing 300 to 500 cfm is sufficient to remove all of the HCl and chlorine gas from the chamber and, additionally, to provide a slight negative pressure within it.

The control system consists of (1) a settling chamber, where some agglomeration and settling takes place; (2) a packed-tray-type scrubber utilizing 10 percent caustic solution, where virtually all of the chlorine and nearly all of the HCl is removed, together with the major portion of the remaining particulate matter; and (3) a baghouse, where the remaining particulate is separated from the effluent. Since the particulates are hygroscopic and the gas stream from the scrubber to the baghouse is nearly saturated with water, the effluent must be heated to about 175° F to prevent combustion in the baghouse.

This combination control system has proved successful in controlling demagging emissions; however, maintenance costs are high. All ductwork from the chlorination chamber to the scrubber must be cleaned of settled particulates soon after each chlorination; otherwise, they harden and are very difficult to remove. The packed-tray-type scrubber also should be washed free of all collected particulate after each chlorination. If this is not done, stratification of the effluent and caustic hampers removal of the chlorine and HCl. Then corrosion occurs in the baghouse and on structures near the baghouse.

SECONDARY ZINC-MELTING PROCESSES

Zinc is melted in crucible, pot, kettle, rever-
beratory, or electric-induction furnaces for use
in alloying, casting, and galvanizing and is re-
claimed from higher melting point metals in sweat
furnaces. Secondary refining of zinc is conduc-
ted in retort furnaces, which can also be used to
manufacture zinc oxide by vaporizing and burn-
ing zinc in air. All these operations will be dis-
cussed in this section except the reclaiming of
zinc from other metals by use of a sweat furnace.
Information on this subject can be found in a fol-
lowing section entitled, "Metal Separation Pro-
cesses."

ZINC MELTING

The melting operation is essentially the same in
all the different types of furnaces. In all but the
low-frequency induction furnace, solid metal can
be melted without the use of a molten heel. Once
a furnace is started, however, a molten heel is
generally retained after each tap for the begin-
ning of the next heat.

Zinc to be melted may be in the form of ingots,
reject castings, flashing, or scrap. Ingots, re-
jects, and heavy scrap are generally melted first
to provide a molten bath to which light scrap and
flashing are added. After sufficient metal has
been melted, it is heated to the desired pouring
temperature, which may vary from 800° to
1,100°F. Before the pouring, a flux is added and
the batch agitated to separate the dross accumu-
lated during the melting operation. Dross is
formed by the impurities charged with the metal
and from oxidation during the melting and heating
cycles. The flux tends to float any partially sub-
merged dross and conditions it so that it can be
skimmed from the surface. When only clean in-
got is melted, very little, if any, fluxing is nec-
essary. On the other hand, if dirty scrap is
melted, large amounts of fluxes are needed. Af-
ter the skimming, the melt is ready for pouring
into molds or ladles. No fluxing or special pro-
cedures are employed while the zinc is being
poured.

The Air Pollution Problem

The discharge of air contaminants from melting
furnaces is generally caused by excessive tem-
peratures and by the melting of metal contami-
nated with organic material. Fluxing can also
create excessive emissions, but fluxes are avail-
able that clean the metal without fuming.

Probably the first visible discharge noted from
a furnace is from organic material. Before the
melt is hot enough to vaporize any zinc, accom-

panying organic material is either partially ox-
idized or vaporized, causing smoke or oily mists
to be discharged. This portion of the emissions
can be controlled either by removing the organic
material before the charging to the furnace or by
completely burning the effluent in a suitable in-
cinerator or afterburner.

Normally, zinc is sufficiently fluid for pouring
at temperatures below 1,100°F. At that temper-
ature, its vapor pressure is 15.2 millimeters of
mercury, low enough that the amount of fumes
formed cannot be seen. If the metal is heated
above 1,100°F, excessive vaporization can occur
and the resulting fumes need to be controlled with
an air pollution control device. Zinc can vapor-
ize and condense as metallic zinc if existing tem-
peratures and atmospheric conditions do not pro-
mote oxidation. Finely divided zinc so formed
is a definite fire hazard, and fires have occurred
in baghouses collecting this material.

Many fluxes now in use do not fume, and air con-
taminants are not discharged. In some cases,
however, a specific fuming flux may be needed,
in which case a baghouse is required to collect
the emissions. An example of a fuming flux is
ammonium chloride, which, when heated to the
temperature of molten zinc, decomposes into
ammonia and hydrogen chloride gases. As the
gases rise into the atmosphere above the molten
metal, they recombine, forming a fume consisting
of very small particles of ammonium chloride.

Provided the temperature of the melt does not
exceed 1,100°F, there should be no appreciable
amounts of air contaminants discharged when the
zinc is poured into molds. Some molds, how-
ever, especially in die casting, are coated with
mold release compounds containing oils or other
volatile material. The heat from the metal va-
porizes the oils, creating air contaminants. Re-
cently mold release compounds have been de-
veloped that do not contain oils, and this source
of air pollution is thereby eliminated.

ZINC VAPORIZATION

Retort furnaces are used for operations involving
the vaporization of zinc including (1) reclaiming
zinc from alloys, (2) refining by distillation,
(3) recovering zinc from its oxide, (4) manufac-
turing zinc oxide, and (5) manufacturing pow-
dered zinc.

Three basic types of retort furnaces are used in
Los Angeles County: (1) Belgian retorts, (2) dis-
tillation retorts (sometimes called bottle retorts),
and (3) muffle furnaces. Belgian retorts are
used to reduce zinc oxide to metallic zinc. Dis-
tillation retorts, used for batch distillations, re-
claim zinc from alloys, refine zinc, make pow-
dered zinc, and make zinc oxide. Muffle fur-
naces, used for continuous distillation, reclaim

zinc from alloys, refine zinc, and make zinc oxide.

Although zinc boils at 1,665°F, most retort furnaces are operated at temperatures ranging from 1,800° to 2,280°F. Zinc vapor burns spontaneously in air; therefore, air must be excluded from the retort and condenser when metallic zinc is the desired product. Condensers are designed, either for rapid cooling of the zinc vapors to a temperature below the melting point to produce powdered zinc, or for slower cooling to a temperature above the melting point to produce liquid zinc. When the desired product is zinc oxide, the condenser is bypassed and the vapor is discharged into a stream of air where spontaneous combustion converts the zinc to zinc oxide. Excess air is used, not only to ensure sufficient oxygen for the combustion, but also to cool the products of combustion and convey the oxide to a suitable collector.

REDUCTION RETORT FURNACES

Reduction in Belgian Retorts

The Belgian retort furnace is one of several horizontal retort furnaces that have been for many years the most common device for the reduction of zinc. Although the horizontal retort process is now being replaced by other methods capable of handling larger volumes of metal per retort and by the electrolytic process for the reduction of zinc ore, only Belgian retorts are used in the Los Angeles area. In this area, zinc ores are not reduced; the reduction process is used to reclaim zinc from the dross formed in zinc-melting operations, the zinc oxide collected by air pollution control systems serving zinc alloy-melting operations, and the contaminated zinc oxide from zinc oxide plants.

A typical Belgian retort (Figure 202) is about 8 inches in internal diameter and from 48 to 60 inches long. One end is closed and a conical shaped clay condenser from 18 to 24 inches long is attached to the open end. The retorts are arranged in banks with rows four to seven high and as many retorts in a row as are needed to obtain the desired production. The retorts are generally gas fired.

The retorts are charged with a mixture of zinc oxide and powdered coke. Since these materials are powdered, water is added to facilitate charging and allow the mixture to be packed tightly into the retort. From three to four times more carbon is used than is needed for the reduction reaction.

After the charging, the condensers are replaced and their mouths stuffed with a porous material. A small hole is left through the stuffing to allow moisture and unwanted volatile materials to escape. About 3 hours are needed to expel all the undesirable volatile materials from the retort. About 6 hours after charging is completed, zinc vapors appear. The charge in the retort is brought up to 1,832° to 2,012°F for about 8 hours, after which it may rise slowly to a maximum of 2,280°F. The temperature on the outside of the retorts ranges from 2,375° to 2,550°F. The condensers are operated at from 780° to 1,020°F, a temperature range above the melting point of zinc but where the vapor pressure is so low that a minimum of zinc vapor is lost.

The reduction reaction of zinc oxide can be summarized by the reaction:

$$ZnO + C = Zn + CO \qquad (101)$$

Very little, if any, zinc oxide is, however, actually reduced by the solid carbon in the retort. A series of reactions results in an atmosphere rich in carbon monoxide, which does the actual reducing. The reactions are reversible, but by the use of an excess of carbon, they are forced toward the right. The reactions probably get started by the oxidation of a small portion of the coke by the oxygen in the residual air in the retort. The oxygen is quickly used, but the carbon dioxide formed reacts with the carbon to form carbon monoxide according to the equation:

$$CO_2 + C = 2CO \qquad (102)$$
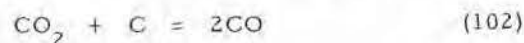
The carbon monoxide in turn reacts with zinc oxide to produce zinc and carbon dioxide:

$$CO + ZnO = Zn + CO_2 \qquad (103)$$

Carbon monoxide is regenerated by use of equation 102, and the reduction of the zinc oxide proceeds.

About 8 hours after the first zinc begins to be discharged, the heat needed to maintain production begins to increase and the amount of zinc produced begins to decrease. Although zinc can still be produced, the amount of heat absorbed by the reduction reaction decreases and the temperature of the retort and its contents increases. Care must be taken not to damage the retort or fuse its charge. As a result, a 24-hour cycle has been found to be an economical operation. The zinc values still in the spent charge are recovered by recycling with the fresh charges. A single-pass recovery yields 65 to 70 percent of the zinc charged, but, by recycling, an overall recovery of 95 percent may be obtained.
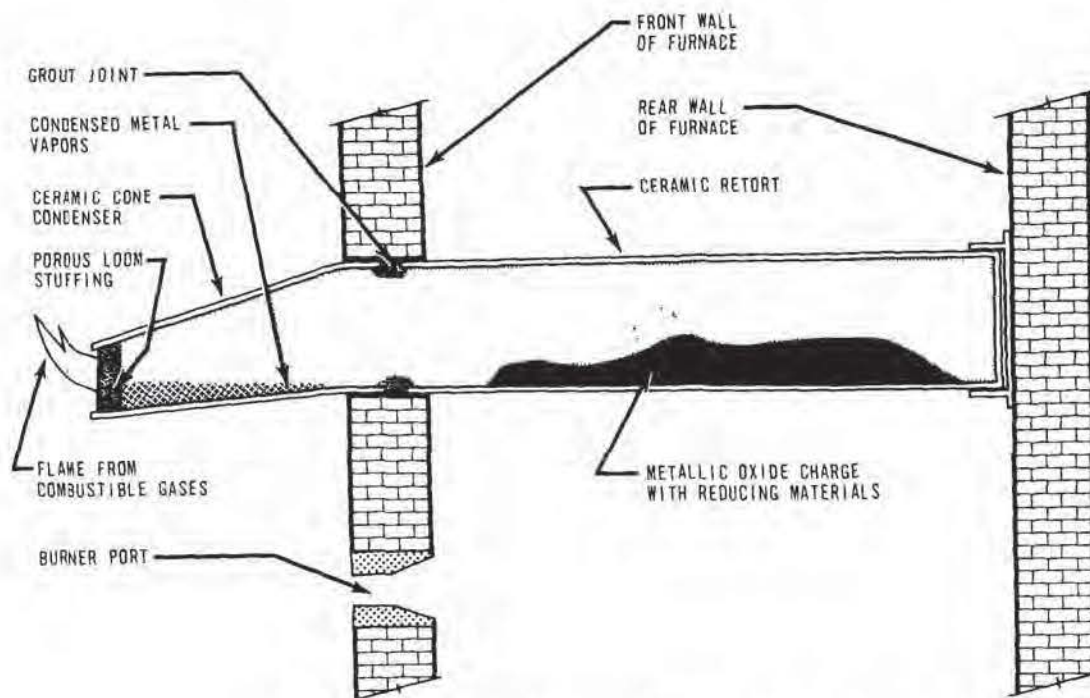
Figure 202. Diagram showing one bank of a Belgian retort furnace.

The Air Pollution Problem

The air contaminants emitted vary in composition and concentration during the operating cycle of Belgian retorts. During charging operation very low concentrations are emitted. The feed is moist and, therefore, not dusty. As the retorts are heated, steam is emitted. After zinc begins to form, both carbon monoxide and zinc vapors are discharged. These emissions burn to form gaseous carbon dioxide and solid zinc oxide. During the heating cycle, zinc is poured from the condensers about three times at 6- to 7-hour intervals. The amount of zinc vapors discharged increases during the tapping operation. Before the spent charge is removed from the retorts, the temperature of the retorts is lowered, but zinc fumes and dust from the spent charge are discharged to the atmosphere.

Hooding and Ventilation Requirements

Air contaminants are discharged from each retort. In one installation, a furnace has 240 retorts arranged in five horizontal rows with 48 retorts per row. The face of the furnace measures 70 feet long by 8 feet high; therefore, the air contaminants are discharged from 240 separate openings and over an area of 560 square feet. A hood 2 feet wide by 70 feet long positioned immediately above the front of the furnace is used to collect the air contaminants. The hood indraft is 175 fpm.

DISTILLATION RETORT FURNACES

The distillation retort furnace (Figure 203) consists of a pear-shaped, graphite retort, which may be 5 feet long by 2 feet in diameter at the closed end by 1-1/2 feet in diameter at the open end and 3 feet in diameter at its widest cross-section. Normally, the retort is encased in a brick furnace with only the open end protruding and it is heated externally with gas- or oil-fired burners. The retorts are charged with molten, impure zinc through the open end, and a condenser is attached to the opening to receive and condense the zinc vapors. After the distillation is completed, the condenser is moved away, the residue is removed from the retort, and a new batch is started.

The vaporized zinc is conducted either to a condenser or discharged through an orifice into a stream of air. Two types of condensers are used — a brick-lined steel condenser operated at from 780° to 1,012° F to condense the vapor to liquid zinc, or a larger, unlined steel condenser that cools the vapor to solid zinc. The latter condenser is used to manufacture powered zinc. The condensers must be operated at a slight positive pressure to keep air from entering them and
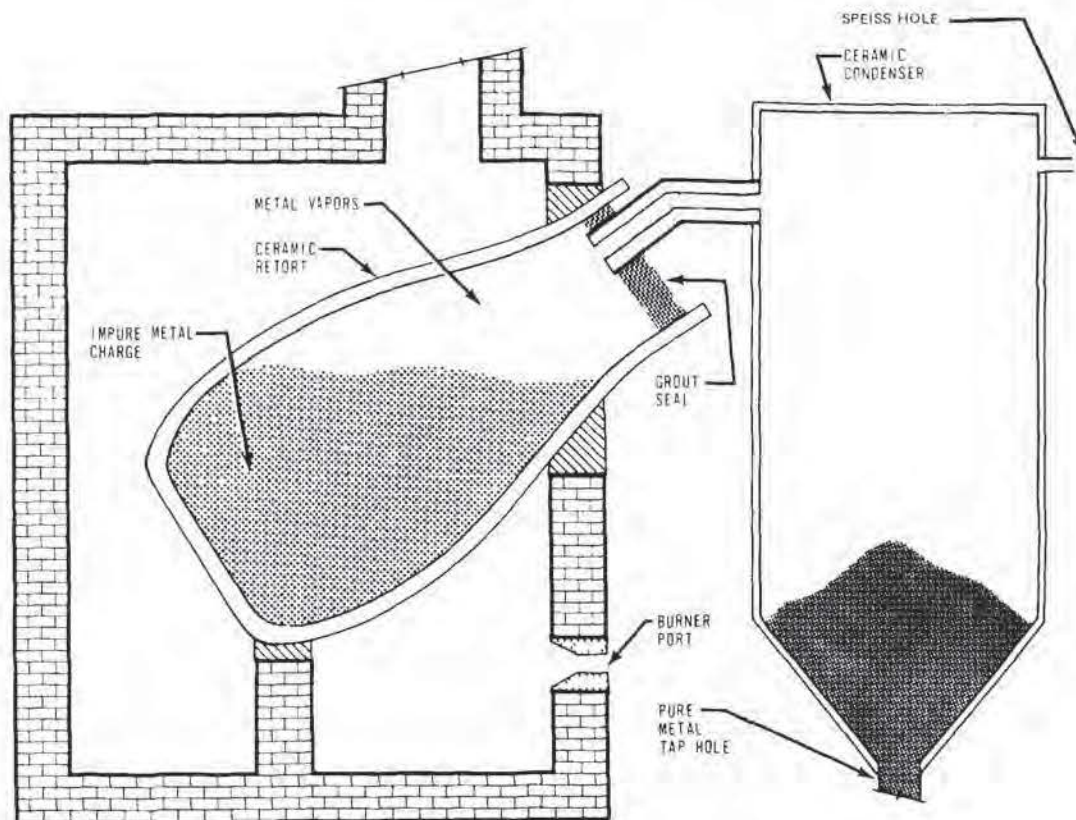
Figure 203. Diagram of a distillation-type retort furnace.

oxidizing the zinc. To ensure that there is a pos-
itive pressure, a small hole, called a "speiss"
hole, is provided through which a small amount
of zinc vapor is allowed to escape continuously
into the atmosphere. The vapor burns with a
bright flame, indicating that there is a pressure
in the condenser. If the flame gets too large, the
pressure is too high. If it goes out, the pressure
is too low. In either case, the proper adjust-
ments are made to obtain the desired condenser
pressure.

When it is desired to make zinc oxide, the vapor
from a retort is discharged through an orifice
into a stream of air where zinc oxide is formed
inside a refractory-lined chamber. The com-
bustion gases and air, which bear the oxide par-
ticles, are then carried to a baghouse collector
where the powdered oxide is collected.

The Air Pollution Problem

During the 24-hour cycle of the distillation re-
torts, zinc vapors escape from the retort (1) when
the residue from the preceding batch is removed
from the retort and a new batch is charged, and
(2) when the second charge is added to the retort.
As the zinc vapors mix with air, they oxidize and

form a dense cloud of zinc oxide fumes. Air con-
taminants are discharged for about 1 hour each
time the charging hole is open. When the zinc is
actually being distilled, no fumes escape from
the retort; however, a small amount of zinc oxide
escapes from the speiss hole in the condenser.
Although the emission rate is low, air contami-
nants are discharged for about 20 hours per day.

Hooding and Ventilation Requirements

To capture the emissions from a distillation re-
tort furnace, simple canopy hoods placed close
to and directly over the sources of emissions are
sufficient. In the only installation in Los Angeles
County, the charging end of the retort protrudes
a few inches through a 4-foot-wide, flat wall of
the furnace. The hood is 1 foot above the retort,
extends 1-1/4 feet out from the furnace wall, and
is 4 feet wide. The ventilation provided is 2,000
cfm, giving a hood indraft of 400 fpm. Fume
pickup is excellent. The speiss hole is small
and all the fumes discharged are captured by a
1-foot-diameter hood provided with 200 cfm ven-
tilation. The hood indraft is 250 fpm.

The retorts are gas fired and the products of
combustion do not mix with the emissions from

the retort or the condenser. The exhausted gases are heated slightly by the combustion of zinc and from radiation and convection losses from the retort, but the amount of heating is so low that no cooling is necessary.

MUFFLE FURNACES

Muffle furnaces (Figure 204) are continuously fed retort furnaces. They generally have a much greater vaporizing capacity than either Belgian retorts or bottle retorts do, and they are operated continuously for several days at a time. Heat for vaporization is supplied by gas- or oil-fired burners by conduction and radiation through a silicon carbide arch that separates the zinc vapors and the products of combustion. Molten zinc from either a melting pot or sweat furnace is charged through a feed well that also acts as an air lock. The zinc vapors are conducted to a condenser where purified liquid zinc is collected, or the condenser is bypassed and the vapors are discharged through an orifice into a stream of air where zinc oxide is formed.

A muffle furnace installation in Los Angeles County consists of three identical furnaces, each capable of vaporizing several tons of zinc per day. These furnaces can produce zinc of 99.99 percent purity and zinc oxide of 99.95 percent purity from zinc alloys. Each furnace has three sections: (1) A vaporizing chamber, (2) a condenser, and (3) a sweating chamber. Figure 205 shows the feed ends of the furnaces, including the sweating chambers, and some of the ductwork and hoods serving the furnaces.

Each furnace, including the feed well and sweating chamber, is heated indirectly with a combination gas- or oil-fired burner. The combustion chamber, located directly over the vaporizing chamber, is heated to about 2,500°F. On leaving the combustion chamber, the products of combustion are conducted over the zinc feed well and through the sweating chamber to supply the heat needed for melting the zinc alloys from the scrap charged and for heating the zinc in the feed well to about 900°F.

Zinc vapors are conducted from the vaporizing section into a multiple-chamber condenser. When zinc oxide is the desired product, the vapors are allowed to escape through an orifice at the top of the first chamber of the condenser. Even when maximum zinc oxide production is desired, some molten zinc is nevertheless formed and collects in the condenser.

When metallic zinc is the desired product, the size of the orifice is greatly reduced, but not entirely closed, so that most of the vapors enter the second section of the condenser where they condense to molten zinc. The molten zinc collected in the condenser is held at about 900°F in a well, from which it is periodically tapped. The well and the tap hole are so arranged that sufficient molten zinc always remains in the well to maintain an air lock.

The zinc that escapes from the orifice while molten zinc is being made burns to zinc oxide, which is conducted to the product baghouse.

The Air Pollution Problem

Dust and fumes are created by the sweating operation. Scrap is charged into the sweating chamber through the door shown in Figure 205. After the
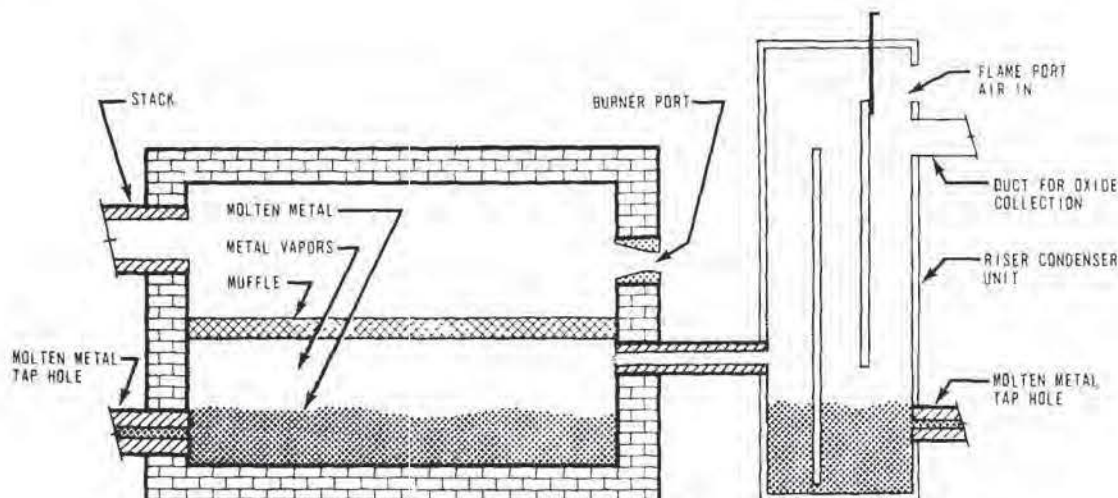

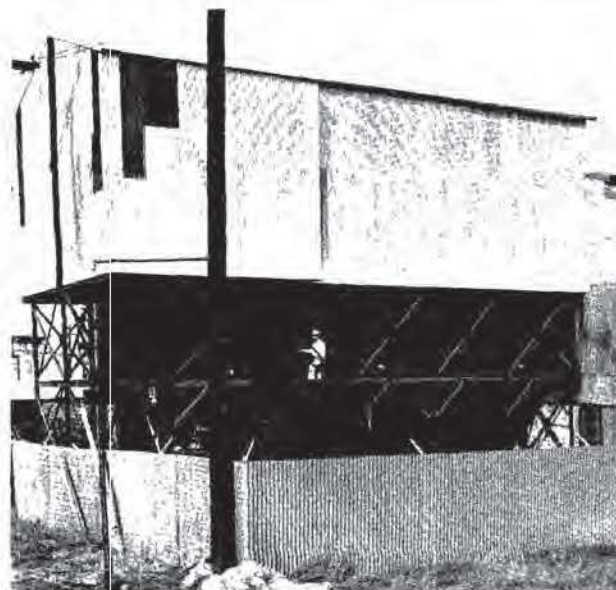Figure 204. Diagram of a muffle furnace and condenser.

Figure 205. (Left) Zinc-vaporizing muffle furnaces. (right) baghouse for collecting the zinc oxide manufactured (Pacific Smelting Co., Torrance, Calif.).

zinc alloys have been melted, the residue is pushed out of the chamber through a second door and onto a shaker screen where dross is separated from solid metal. Excessive dust and fumes are thereby created.

The zinc alloys charged into the vaporizing section contain copper, aluminum, iron, lead, and other impurities. As zinc is distilled from the metals, the concentration of the impurities increases until continued distillation becomes impractical. After 10 to 14 days of operation, the residue, containing 10 to 50 percent zinc must be removed. When tapped, the temperature of the residue is about 1,900°F, hot enough to release zinc oxide fumes. The molds collecting the residue metal are so arranged that the metal overflows from one mold to another; however, the metal cools so rapidly that fumes are released only from the pouring spout and the first two or three molds. The fumes, almost entirely zinc oxide, are 100 percent opaque from the pouring spout and the first mold. At the third mold, the opacity decreases to 10 percent.

Any discharge of zinc vapor from the condenser forms zinc oxide of product purity; therefore, the condenser vents into the intake hood of a product-collecting exhaust system. Since some zinc oxide is always produced, even when the condenser is set to produce a maximum of liquid zinc, the product-collecting exhaust system is always in operation to prevent air contaminants from escaping from the condenser to the atmosphere.

Hooding and Ventilation Requirements

The dust and fumes created by the charging of scrap and the sweating of zinc alloys from the scrap originate inside the sweat chamber. The thermal drafts cause the emissions to escape from the upper portion of the sweat chamber doors. Hoods are placed over the doors to collect the emissions. The charging door hood extends 10 inches from the furnace wall and covers a little more than the width of the door (see Figure 205). With two furnaces in operation at the same time, each of the charging door hoods is supplied with 3,200 cfm ventilation, which provides an indraft velocity of 700 fpm. All fumes escaping from the charging doors are collected by these hoods.

The unmelted scrap and dross are raked from a sweating chamber onto a shaker screen. A hood enclosing the discharge lip and the screen is provided with 5,500 cfm ventilation. The inlet velocity is 250 fpm, sufficient to capture all of the emissions escaping from both the furnace and the screen.

A hood 3 feet square positioned over the residue metal-tapping spout and the first mold is provided with 8,700 cfm ventilation. During the tapping, no metal is charged to either sweating chamber, and the exhaust system dampers are arranged so that approximately one-half of the available volume is used at the tapping spout. The indraft velocity is in excess of 900 fpm, and all

fumes released from the metal are collected, even from the second and third molds up to 6 feet away from the hood.

The ductwork joining the hoods to the control devices is manifolded and dampered so that any or all hoods can be opened or closed. The exhaust system provides sufficient ventilation to control the fumes created by two furnaces in operation at the same time. When residue metal is being tapped from a furnace, no metal is being charged to the other furnaces; therefore, all the ventilation, or as much as is needed, can be used at the tapping hood.

AIR POLLUTION CONTROL EQUIPMENT

For all the furnaces mentioned in this section, that is reduction retort furnaces, distillation retort furnaces, and muffle furnaces, air pollution control is achieved with a baghouse. In the above-mentioned installation for a muffle furnace, a low-efficiency cyclone and a baghouse are used to control the emissions from the sweating chambers and residue pouring operations of the three muffle furnaces. Although the cyclone has a low collection efficiency, it does collect from 5 to 10 percent of the dust load and it is still used. The cyclone was in existence before the baghouse was installed.

The baghouse is a six-section, pull-through type using 5,616 square feet of glass cloth filtering area. The filtering velocity is 3 fpm and the bags are cleaned automatically at regular intervals by shutting off one section, which allows the bags to collapse. No shaking is required, and the collected material merely drops into the hopper below the bags.

Another exhaust system with a cyclone and baghouse is used to collect the zinc oxide manufactured by the muffle furnaces. The system has three inlet hoods, one for each furnace, and each is arranged to collect the zinc vapors discharged from the orifice in the condenser. The ductwork is manifolded into a single duct entering the cyclone, and dampers are provided so that any one or any combination of the hoods can be used at one time. Since the exhausted gases and zinc oxide are heated by the combustion of zinc and by the sensible heat in the zinc, about 350 feet of additional ductwork is provided to allow the exhausted material to cool down to 180°F before entering the baghouse.

The cyclone collects about 20 percent of the solid materials in the exhaust gases, including all the heavier particles such as vitrified zinc oxide and solid zinc. The baghouse collects essentially all the remaining 80 percent of the solids.

The baghouse collector is actually two standard nine-section baghouses operating in parallel. In this unit, orlon bags with a total of 16,848 square feet of filtering area are used to filter the solids from the gases. A 50-hp fan provides 30,500 cfm ventilation--15,250 cfm for each furnace. The filtering velocity is 1.8 fpm. The bags are cleaned at regular intervals by shutting off one section and shaking the bags for a few seconds. A screw conveyor in the bottom of each hopper conveys the zinc oxide collected to a bagging machine.

This system provides excellent ventilation for the installation. None of the zinc oxide discharging from the condensers escapes collection by the hoods, and no visible emissions can be seen escaping from the baghouse.

Dust collectors for other zinc-melting and zinc-vaporizing furnaces are very similar to the ones already described. Glass bags have been found adequate when gas temperatures exceed the limits of cotton or orlon. Filtering velocities of 3 fpm are generally employed and have been found adequate.

LEAD REFINING

Control of the air pollution resulting from the secondary smelting and reclaiming of lead scrap may be conveniently considered according to the type of furnace employed. The reverberatory, blast, and pot furnaces are the three types most commonly used. In addition to refining lead, most of the secondary refineries also produce lead oxide by the Barton process.

Various grades of lead metal along with the oxides are produced by the lead industry. The grade of product desired determines the type of equipment selected for its manufacture. The most common grades of lead produced are soft, semisoft, and hard. By starting with one of these grades and using accepted refining and alloying techniques, any special grade of lead or lead alloy can be made.

Soft lead may be designated as corroding, chemical, acid copper, or common desilverized lead. These four types are high-purity leads. Their chemical requirements are presented in Table 85. These leads are the products of the pot furnace after a considerable amount of refining has been done.

Semisoft lead is the product of the reverberatory-type furnace and usually contains from 0.3 to 0.4 percent antimony and up to 0.05 percent copper.

Hard lead is made in the blast furnace. A typical composition for hard lead is 5 to 12 percent

Table 85. CHEMICAL REQUIREMENTS FOR LEAD[a]
(ASTM Standards, Part 2 1958)

	Corroding lead	Chemical lead	Acid-copper lead	Common desilverized lead
Silver, max %	0.0015	0.020	0.002	0.002
Silver, min. %		0.002		
Copper, max %	0.0015	0.080	0.080	0.0025
Copper, min. %		0.040	0.040	
Silver and copper together, max %	0.0025		0.040	
Arsenic, antimony, and tin together, max %	0.002	0.002	0.002	0.005
Zinc, max %	0.001	0.001	0.001	0.002
Iron, max %	0.002	0.002	0.002	0.002
Bismuth, max %	0.050	0.005	0.025	0.150
Lead (by difference), min. %	99.94	99.90	99.90	99.85

[a]Corroding lead is a designation used in the trade for many years to describe lead refined to a high degree of purity.

Chemical lead is a term used in the trade to describe the undesilverized lead produced from Southeastern Missouri ores.

Acid-copper lead is made by adding copper to fully refined lead.

Common desilverized lead is a designation used to describe fully refined desilverized lead.

antimony, 0.2 to 0.6 percent arsenic, 0.5 to 1.2 percent tin, 0.05 to 0.15 percent copper, and 0.001 to 0.01 percent nickel.

REVERBERATORY FURNACES

Sweating operations are usually conducted in a reverberatory-type furnace or tube. This type of operation is discussed later in this chapter in a section on "Metal Separation Processes." The reverberatory furnace is also used to reclaim lead from oxides and drosses. Very often material for both sweating and reducing such as lead scrap, battery plates, oxides, drosses, and lead residues are charged to a reverberatory furnace. The charges are made up of a mixture of these materials and put into the furnace in such a manner as to keep a very small mound of unmelted material on top of the bath. As the mound becomes molten, more material is charged. This type of furnace may be gas fired or oil fired, or a combination of both. The temperature is maintained at approximately 2,300°F. Only sufficient draft is pulled to remove the smoke and fumes and still allow the retention of as much heat as possible

over the hearth. The molten metal is tapped off at intervals as a semisoft lead as the level of the metal rises. This operation is continuous, and recovery is generally about 10 to 12 pounds of metal per hour per square foot of hearth area.

The Air Pollution Problem

A fairly high percentage of sulfur is usually present in various forms in the charge to the reverberatory furnace. The temperature maintained is sufficiently high to "kill" the sulfides and results in the formation of sulfur dioxide and sulfur trioxide in the exit gases. Also present in the smoke and fumes produced are oxides, sulfides, and sulfates of lead, tin, arsenic, copper, and antimony. An overall material balance shows on the product side approximately 47 percent recovery of metal, 46 percent recovery of slag sometimes called "litharge," and 7 percent of smoke and fumes.

The unagglomerated particulate matter emitted from secondary lead-smelting operations has been found to have a particle size range from 0.07 to 0.4

micron with a mean of about 0.3 micron (Allen et al., 1952). Figure 206 shows electron photomicrographs of lead fumes. The particles are nearly spherical and have a distinct tendency to agglomerate. The concentration of particulate matter in stack gases ranges from 1.4 to 4.5 grains per cubic foot.

Hooding and Ventilation Requirements

All the smoke and fumes produced by the reverberatory furnace must be collected and, since they are combined with the products of combustion, the entire volume emitted from the furnace must pass through the collector. It is not desirable to draw cool air into these furnaces through the charge doors, inspection ports, or other openings to keep air contaminants from escaping from them; therefore, external hoods are used to capture these emissions. The ventilating air for these hoods as well as for the hoods venting slag stations must also pass through the collector. In large furnaces, this represents a considerable volume of gases at fairly high temperatures.

Air Pollution Control Equipment

The only control systems found to operate satisfactorily in Los Angeles County have been those

Figure 206. Electron photomicrographs of lead fumes (Allen et al., 1952).

employing a baghouse as a final collector. These systems also include auxiliary items such as gas-cooling devices and settling chambers.

A pull-through type of baghouse with compartments that can be shut off one at a time is very satisfactory. This allows atmospheric air to enter one compartment and relieve any flow. The bags may then be cleaned by a standard mechanical shaking mechanism.

Provision should be made to prevent sparks and burning materials from contacting the filtercloth, and temperature must be controlled by preceding the baghouse with radiant cooling ducts, water-jacketed cooling ducts, or other suitable devices in order that the type of cloth used will have a reasonable life. The type of cloth selected depends upon parameters such as the temperature and corrosivity of the entering gases, and the permeability and abrasion- or stress-resisting characteristics of the cloth. Dacron bags are being successfully used in this service. The filtering velocity should not exceed 2 fpm. Test results of secondary lead-smelting furnaces venting to a baghouse control device are shown in Table 86.

The factors to be considered in designing these control systems are similar to those discussed previously in the sections on iron casting and steel manufacturing.

LEAD BLAST FURNACES

The lead blast furnace or cupola is constructed similarly to those used in the ferrous industry. The materials forming the usual charge for the blast furnace, and a typical percentage composition are 4.5 percent rerun slag, 4.5 percent scrap cast iron, 3 percent limestone, 5.5 percent coke, and 82.5 percent drosses, oxides, and reverberatory slags. The rerun slag is the highly silicated slag from previous blast furnace runs. The drosses are miscellaneous drosses consisting of copper drosses, caustic drosses, and dry drosses obtained from refining processes in the pot furnaces. The processes will be described in more detail in the following paragraphs. The coke is used as a source of heat, and combustion air is introduced near the bottom of the furnace through tuyeres at a gage pressure of about 8 to 12 ounces per square inch. Hard lead is charged into the cupola at the start of the operation to provide molten metal to fill the crucible. Normal charges, as outlined previously, are then added as the material melts down. The limestone and iron form the flux that floats on top of the molten lead and retards its oxidation.

As the level of molten material rises, the slag is tapped at intervals while the molten lead flows from the furnace at a more or less continuous rate. The lead product is "hard" or "antimonial." Approximately 70 percent of the molten material is tapped off as hard lead, and the remaining 30 percent, as slag. About 5 percent of the slag is retained for rerun later.

The Air Pollution Problem

Combustion air from the tuyeres passing vertically upward through the charge in a blast furnace conveys oxides, smoke, bits of coke fuel, and other particulates present in the charge. A typical material balance based upon the charge to a blast furnace in which battery groups are being processed is 70 percent recovery of lead, 8 percent slag, 10 percent matte (sulfur compounds formed with slag), 5 percent water (moisture contained in charge), and 7 percent dust (lead oxide and other particulates discharged from stack of furnace with gaseous products of combustion). Particulate matter loading in blast furnace gases is exceedingly heavy, up to 4 grains per cubic foot. The particle size distribution is very similar to that from gray iron cupolas, as described previously in the section on "Iron Casting."

Blast furnace stack gas temperatures range from 1,200° to 1,350°F. In addition to the particulate matter, which consists of smoke, oil vapor, fume, and dust, the blast furnace stack gases contain carbon monoxide. An afterburner is necessary to control the gaseous, liquid, and solid combustible material in the effluent.

Hooding and Ventilation Requirements

The only practical way to capture the contaminants discharged from a lead blast furnace is to seal the furnace and vent all the gases to a control system. The hooding and ventilation requirements are very similar to those for the gray iron cupola, which are discussed in the section on "Iron Casting."

Air Pollution Control Equipment

The control system for a lead blast furnace is similar to that employed for gray iron cupola furnaces except that electrical precipitators are not used for economic reasons. Moreover, difficulties are encountered in conditioning the particles to give them resistivity characteristics in the range that will allow efficient collection.

The factors to be considered in designing a control system for a blast furnace, including an afterburner and a baghouse, have been discussed in the section on "Iron Casting."

Table 86. DUST AND FUME EMISSIONS FROM A SECONDARY LEAD-SMELTING FURNACE

Test No.	1	2
Furnace data		
Type of furnace	Reverberatory	Blast
Fuel used	Natural gas	Coke
Material charged	Battery groups	Battery groups, dross, slag
Process weight, lb/hr	2,500	2,670
Control equipment data		
Type of control equipment	Sectioned tubular baghouse[a]	Sectioned tubular baghouse[a]
Filter material	Dacron	Dacron
Filter area, ft^2	16,000	16,000
Filter velocity, fpm at 327°F	0.98	0.98
Dust and fume data		
Gas flow rate, scfm		
Furnace outlet	3,060	2,170
Baghouse outlet	10,400[b]	13,000[b]
Gas temperature, °F		
Furnace outlet	951	500
Baghouse outlet	327	175
Concentration, gr/scf		
Furnace outlet	4.98	12.3
Baghouse outlet	0.013	0.035
Dust and fume emission, lb/hr		
Furnace outlet	130.5	229
Baghouse outlet	1.2	3.9
Baghouse efficiency, %	99.1	98.3
Baghouse catch, wt %		
Particle size 0 to 1 μ	13.3	13.3
1 to 2	45.2	45.2
2 to 3	19.1	19.1
3 to 4	14.0	14.0
4 to 16	8.4	8.4
Sulfur compounds as SO_2, vol %		
Baghouse outlet	0.104	0.03

[a]The same baghouse alternately serves the reverberatory furnace and the blast furnace.
[b]Dilution air admitted to cool gas stream.

POT-TYPE FURNACES

Pot-type furnaces are used for remelting, alloying, and refining processes. Remelting is usually done in small pot furnaces, and the materials charged are usually alloys in the ingot form, which do not require any further processing except to be melted for casting operations.

The pots used in the secondary smelters range from the smallest practical size of 1-ton capacity up to 50 tons. Figure 207 is a photograph of two pot furnaces utilizing a common ventilation hood. These furnaces are usually gas fired. Various refining and alloying operations are carried on in these pots. Alloying usually begins with a metal lower in the percentage of alloying materials than desired. The percent desired is calculated and the amount is then added. Antimony, tin, arsenic, copper, and nickel are the most common alloying elements used.

The refining processes most commonly employed are those for the removal of copper and antimony to produce soft lead, and those for the removal of arsenic, copper, and nickel to produce hard lead. For copper removal, the temperature of the molten lead is allowed to drop to 620°F and sulfur is added. The mixture is agitated and copper sulfide is skimmed off as dross. This is known as "copper dross" and is charged into the blast furnace.

When aluminum is added to molten lead, it reacts preferentially with copper, antimony, and nickel to form complex compounds that can be skimmed from the surface of the metal. The antimony content can also be reduced to about 0.02 percent by bubbling air through the molten lead. It can be

Figure 207. An installation used to capture emissions from two lead pot furnaces. Hood serves either furnace alternately (Morris P. Kirk & Son, Inc., Los Angeles, Calif.).

further reduced by adding a mixture of sodium nitrate and sodium hydroxide and skimming the resulting dross from the surface of the metal.

Another common refining procedure, "dry dross-ing," consists of introducing sawdust into the agitated mass of molten metal. This forms carbon, which aids in separating the globules of lead suspended in the dross, and reduces some of the lead oxide to elemental lead.

In areas where there is no great concern about air pollution, a mixture of sal ammoniac and rosin may be used to clean the metal of impurities. This method, however, produces copious quantities of dense, white fumes, and obnoxious odors. In areas having air pollution laws, this method is generally no longer used.

The Air Pollution Problem

Although the quantity of air contaminants discharged from pot furnaces as a result of remelting, alloying, and refining is much less than that from reverberatory or blast furnaces, the capture and control of these contaminants is equally important in order to prevent periodic violations of air pollution regulations and protect the health of the employees.

Problems of industrial hygiene are inherent in this industry. People working with this equipment frequently inhale and ingest lead oxide fumes,

which are cumulative, systemic poisons. Frequent medical examinations are necessary for all employees, and a mandatory dosage of calcium disodium versenate may be required daily in order to keep the harmful effects to a minimum.

Hooding and Ventilation Requirements

Hood design procedures for pot furnaces are the same as those outlined for electric-induction furnaces mentioned earlier in this chapter.

Air Pollution Control Equipment

The control systems for pot furnaces, as with the other lead furnaces, require the use of a baghouse for the final collector. The temperature of the gases is, however, generally much lower than that from the other furnaces; therefore, the gas-cooling devices, if needed, will be much smaller. Afterburners are generally not required.

BARTON PROCESS

A rather specialized phase of the industry is the production of lead oxide. Battery lead oxide, containing about 20 percent finely divided free lead, is usually produced by the Barton process. Molten lead is run by gravity from a melting pot into a kettle equipped with paddles. The paddles are rotated at about 150 rpm, rapidly agitating the molten lead, which is at a temperature of 700° to 900°F. Air is drawn through the kettles by fans located on the air outlet side of a baghouse. The lead oxide thus formed is conveyed pneumatically to the baghouse where it is collected and delivered by screw conveyor to storage.

Other lead oxides requiring additional processing but commonly made are red lead oxide (minium, Pb_3O_4), used in the paint industry, and yellow lead oxide (litharage or massicot, PbO), used in the paint and ink industries.

Since the process requires the use of a baghouse to collect the product, and no other contaminants are discharged, no air pollution control system as such is needed.

METAL SEPARATION PROCESSES

In addition to the metallurgical processes previously mentioned in this chapter, there are other processes classified as metal separation that can be troublesome from an air pollution standpoint. In these, the metal desired is recovered from scrap, usually a mixture of several metals. Probably the most common of these processes, aluminum sweating, is the recovery of aluminum from aluminum drosses and other scrap. Other

examples of metal separation processes include the recovery processes for zinc, lead, solder, tin, and low-melting alloys from a host of scrap materials.

ALUMINUM SWEATING

Open-flame, reverberatory-type furnaces are used by secondary smelters to produce aluminum pigs for remelting. These furnaces are constructed with the hearths sloping downward toward the rear of the furnace. All types of scrap aluminum are charged into one of these furnaces, which operates at temperatures of 1,250° to 1,400°F. In this temperature range, the aluminum melts, trickles down the hearth, and flows from the furnace into a mold. The higher melting materials such as iron, brass, and dross oxidation products formed during melting remain within the furnace. This residual material is periodically raked from the furnace hearth.

Some large secondary aluminum smelters separate the aluminum suspended in the dross by processing the hot dross immediately after its removal from the metal in the refining furnace. The hot dross is raked into a refractory-lined barrel to which a salt-cryolite flux is added. The barrel is placed on a cradle and mechanically rotated for several minutes. Periodically, the barrel is stopped and the metal is tapped by removing a clay plug in the base of the barrel. This process continues until essentially all the free aluminum has been drained and only dry dross remains. The dross is then dumped and removed from the premises. A hot dross-processing station has been illustrated previously in Figure 200.

The aluminum globules suspended in the dross as obtained from the hot dross process can also be separated and reclaimed by a cold, dry, milling process. In this process the large chunks of dross are reduced in size by crushing and then fed continuously to a ball mill where the oxides and other nonmetallics are ground to a fine powder, which allows separation from the larger solid particles of aluminum. At the mill discharge, the fine oxides are removed pneumatically and conveyed to a baghouse for ultimate disposal. The remaining material passes over a magnetic roll to remove tramp iron and is then discharged into storage bins to await melting. This process is used primarily to process drosses having a low aluminum content.

ZINC, LEAD, TIN, SOLDER, AND LOW-MELTING ALLOY SWEATING

Although recovery of aluminum is the most common of the metal separation processes, others

that contribute to air pollution deserve mention. These include zinc, lead, tin, solder, and low-melting alloy sweating. Separation of these metals by sweating is made possible by the differences in their melting point temperatures. Some of these melting temperatures are:

Tin	450°F
Lead	621°F
Zinc	787°F
Aluminum	1,220°F
Copper	1,981°F
Iron	2,795°F

When the material charged to a sweating furnace contains a combination of two of these metals, it can be separated by carefully controlling the furnace temperature so that the metal with the lower melting point is sweated when the furnace temperature is maintained slightly above its melting point. After this metal has been melted and removed, the furnace burners are extinguished and the metal with the higher melting point is raked from the hearth.

Zinc can be recovered by sweating in a rotary, reverberatory, or muffle furnace. Zinc-bearing materials fed to a sweating furnace usually consist of scrap die-cast products such as automobile grilles, license plate frames, and zinc skims and drosses.

The sweating of lead from scrap and dross is widely practiced. Junk automobile storage batteries supply most of the lead. In addition, lead-sheathed cable and wire, aircraft tooling dies, type metal drosses, and lead dross and skims are also sweated. The rotary furnace, or sweating tube, is usually used when the material processed has a low percent of metal to be recovered. The reverberatory box-type furnace is usually used when the percent of metal recovered is high.

Rotary and reverberatory furnaces are also used to sweat solder and other low-melting alloys from scrap metal. Automobile radiators and other soldered articles such as gas meter boxes, radio chassis, and so forth, make up the bulk of the process metal. For this recovery, the furnace is usually maintained between 650°F and 700°F. Higher temperatures should be avoided in order to prevent the possible loss of other recoverable metals. For example, sweating automobile radiators at 900°F causes excessive oxidation of the copper.

The Air Pollution Problem

Contaminants from aluminum-separating processes

In theory, an aluminum-sweating furnace can be operated with minor emissions of air contaminants if clean, carefully hand-picked metal free of organic material is processed. In practice, this selective operation does not occur and excessive emissions periodically result from uncontrolled furnaces. Stray magnesium pieces scattered throughout the aluminum scrap are not readily identified, and charging a small amount of magnesium into a sweating furnace causes large quantities of fumes to be emitted. Emissions also result from the other materials charged, such as skims, drosses, scrap aluminum sheet, pots and pans, aircraft engines, and wrecked airplanes containing oil, insulated wire, seats, instruments, plastic assemblies, magnesium and zinc components, and so forth.

Smoke is caused by the incomplete combustion of the organic constituents of rubber, oil and grease, plastics, paint, cardboard, and paper. Fumes result from the oxidation of stray magnesium or zinc assemblies and from the volatilization of fluxes in the dross. The sweating of dross and skims is responsible for the high rates of emission of dust and fumes. Residual aluminum chloride flux in the dross is especially troublesome because it sublimes at 352°F and is very hygroscopic. In addition, it hydrolyzes and forms very corrosive hydrogen chloride. In Table 87, test 1 shows results from an aluminum-sweating furnace.

In the dry milling process, dust is generated at the crusher, in the mill, at the shaker screens, and at points of transfer. These locations must be hooded to prevent the escape of fine dust to the atmosphere.

When aluminum is reclaimed by the hot dross process, some fumes are emitted from the flux action; however, the main air pollution problem is the collection of the mechanically generated dust created by the rotation of the dross barrel.

Contaminants from low-temperature sweating

Air contaminants released from a zinc-sweating furnace consist mainly of smoke and fumes. The smoke is generated by the incomplete combustion of the grease, rubber, plastics, and so forth contained in the material. Zinc fumes are negligible at low furnace temperatures, for they have a low vapor pressure even at 900°F. With elevated furnace temperatures, however, heavy fuming can result. In Table 87, test 2 shows results from a zinc die-cast-sweating operation.

The discharge from a lead-sweating furnace may be heavy with dust, fumes, smoke, sulfur compounds, and fly ash. This is particularly true when junk batteries are sweated. The battery groups and plates removed from the cases contain bits of asphaltic case, oil and grease around the terminals, sulfuric acid, lead sulfate, lead oxide, and wooden or glass fiber plate separators. The organic contaminants burn poorly and the sulfur compounds release SO_2 and SO_3. The sulfur trioxide is particularly troublesome; when hydrolized to sulfuric acid, the acid mist is difficult to collect and is extremely corrosive. The lead oxide tumbles within the rotating furnace and the finer material is entrained in the vented combustion gases.

Unagglomerated lead oxide fume particles vary in diameter from about 0.07 to 0.4 micron, with a mean of about 0.3 micron (Allen et al., 1952). Uncontrolled rotary lead sweat furnaces emit excessively high quantities of air contaminants. Although the other types of scrap lead and drosses sweated in a reverberatory furnace are normally much less contaminated with organic matter and acid, high emission rates occur periodically.

The contaminants generated during the sweating of solder, tin, and other low-melting alloys consist almost entirely of smoke and partially oxidized organic material. The scrap metal charged is usually contaminated with paint, oil, grease, rust, and scale. Automobile radiators frequently contain residual antifreeze and sealing compounds.

Hooding and Ventilation Requirements

The ventilation and hooding of reverberatory furnaces and rotary furnaces used for the reclamation processes just mentioned are similar to those of furnaces of this type previously discussed in this chapter. The exhaust system must have sufficient capacity to remove the products of combustion at the maximum firing rate and provide adequate collection of the emissions from any furnace opening.

In aluminum separation operations, raking the residual metal and dross from the furnace is a critical operation from an air pollution standpoint, and hoods should be installed to capture emissions at these locations. The required exhaust volume may be effectively reduced by providing a guillotine-type furnace door and opening it only as needed to accomplish charging and raking. If the burners are turned off during these operations, the indraft velocity through the charging and raking opening is effectively increased and the emissions from this location are reduced.

Table 87. DUST AND FUME EMISSIONS FROM ALUMINUM-
AND ZINC-SWEATING FURNACE CONTROLLED BY BAGHOUSE

Test No.	1	2
Furnace data		
Type of furnace	Reverberatory	Reverberatory
Size of furnace		
Width	5 ft 9 in.	5 ft 9 in.
Length	6 ft 4 in.	6 ft 4 in.
Height	4 ft	4 ft
Process weight, lb/hr	760	2,080
Material sweated	Aluminum skims	Zinc castings
Baghouse data		
Type of baghouse	Sectioned tubular	Sectioned tubular
Filter material	Orlon	Orlon
Filter area, ft^2	5,184	5,184
Filter velocity, fpm	1.9	1.85
Precleaner	None	None
Dust and fume data		
Gas flow rate, scfm		
Baghouse inlet	8,620	7,680
Baghouse outlet	9,580	7,420
Average gas temperature, °F		
Baghouse inlet	137	190
Baghouse outlet	104	173
Concentration, gr/scf		
Baghouse inlet	0.124	0.205
Baghouse outlet	0.0138	0.0078
Dust and fume emission, lb/hr		
Baghouse inlet	9.16	13.5
Baghouse outlet	1.13[a]	0.5
Control efficiency, %	87.7[a]	96.3

Test No.	3	
Particle size data	Particle diameter, μ	Cumulative weight, %
Aluminum sweating furnace		
	1.79	4.8
	2.38	10.8
	3.57	24.3
	4.76	37.3
	7.10	55.6
	8.90	65.8
	10.10	70.2
	11.90	76.4
	14.30	82.9
	21.40	83.9
	39.30	95.5
	71.40	99.0

[a]Visible emissions released from the baghouse indicated that a bag had broken
during the latter part of the test.

In low-temperature sweating operations, auxiliary hooding is usually necessary and varies with the type of sweating furnace. For the conventional reverberatory-type furnace, a hood should be installed above the furnace door so that escaping fumes can be captured. The emissions occur both during the normal melting process and during the raking of the residual material from the hearth. A rotary sweating furnace usually needs only a hood over the high end of the tube. In cases where the drosses are fine and dusty, however, a hood is necessary at the discharge end, too.

If the hoods are well designed and no unusual crossdrafts are present, an indraft velocity of 100 to 200 fpm is adequate to prevent the escape of the air contaminants.

Air Pollution Control Equipment

Aluminum-separating processes

Although air pollution control equipment is necessary in aluminum reclamation processes, some operating procedures reduce the quantity of emissions. Whenever possible the stray magnesium pieces and combustible material should be removed from the aluminum scrap to be sweated. The furnace burners should be operated so that the flame does not impinge on the scrap metal, particularly if the burners are oil fired.

An afterburner followed by a baghouse is recommended as control equipment for an aluminum-sweating furnace. Baghouse filtering velocities should not exceed 3 fpm. The afterburner must be so designed that the carbonaceous material is intimately mixed with the exhaust air and held at a suitable temperature for a sufficient length of time to ensure complete incineration. For this service, an afterburner temperature of 1,200° to 1,400°F is recommended with a retention time of the gases in this hot zone of about 0.3 second. A luminous-flame afterburner is generally the most desirable because of the greater flame area. Secondary air may have to be admitted to the afterburner to ensure complete combustion. The afterburner may be constructed as a separate unit from the furnace or may be constructed as an integral part of the furnace somewhat similar to a multiple-chamber incinerator. General design features of afterburners have been discussed in Chapter 5.

The hot gases must be cooled before entering a baghouse, and radiant cooling or dilution with cold air is recommended in preference to evaporative cooling with water. The sweating of aluminum drosses may result in severe corrosion problems owing to the aluminum chloride flux contained in the dross. If the hot furnace gases are cooled with water before entering the baghouse, the aluminum chloride hydrolyzes, producing hydrochloric acid. The ductwork and bags are attacked, rapidly impairing the collection efficiency of the filter. Even the condensation from night air during shutdowns provides sufficient moisture to corrode the equipment in the presence of these chemicals.

Figure 208 shows an aluminum sweating furnace with integral afterburner venting through horizontally positioned radiation-convection cooling columns to a settling chamber and baghouse. The

furnace charging door hood is vented directly to the baghouse. Table 88 shows test data acquired while aluminum scrap heavily contaminated with combustible material was being sweated in the furnace. Combustible carbon was present in the particulate discharge and was coexistent in the vent stream with excess oxygen as shown by the Orsat analysis. This indicates that the rate of combustible discharge from the scrap aluminum was in excess of the incinerating capacity of the afterburner.

In the hot-dross process, the rotating barrel need only be properly hooded and ducted to a baghouse. No afterburning is required, and because of the relatively large indraft air volume, no gas-cooling facilities are required in the exhaust system.

In the dry milling process, the ball mill, crusher, and all transfer points must be hooded and vented to a baghouse in order to prevent the escape of the dust created. The required hood indraft velocities vary from 150 to 500 fpm, depending upon crossdrafts and the force with which the dust is generated. A baghouse filter velocity of 3 fpm or less is recommended. No afterburning or gas-cooling facilities are required in a dry-dross control system.

Low-temperature sweating

An afterburner should be provided to incinerate the combustible matter discharged from a low-temperature sweating furnace.

Since an afterburner cannot remove the noncombustible portion of the effluent, a baghouse should be used with the afterburner to capture the dust and fumes. The maximum recommended baghouse filter velocity is 3 fpm. In certain special applications where the only emissions are oils or other combustible material, an afterburner can be used to incinerate the contaminant, and a baghouse may not be required. Conversely, only a baghouse is required when the process scrap is always free of oils or other combustible waste. Water scrubbers have not proved satisfactory in the collection of metallic fumes of this type.

CORE OVENS

In foundries, core ovens are used to bake the cores used in sand molds. Most cores contain binders that require baking to develop the strength needed to resist erosion and deformation by metal during the filling of the mold. Core ovens supply the heat and, where necessary, the oxygen necessary for the baking. Cores are made in a large variety of sizes and shapes and with a variety of binders; therefore, a variety of types of core ovens are needed to provide the space and heat requirements for baking the cores.
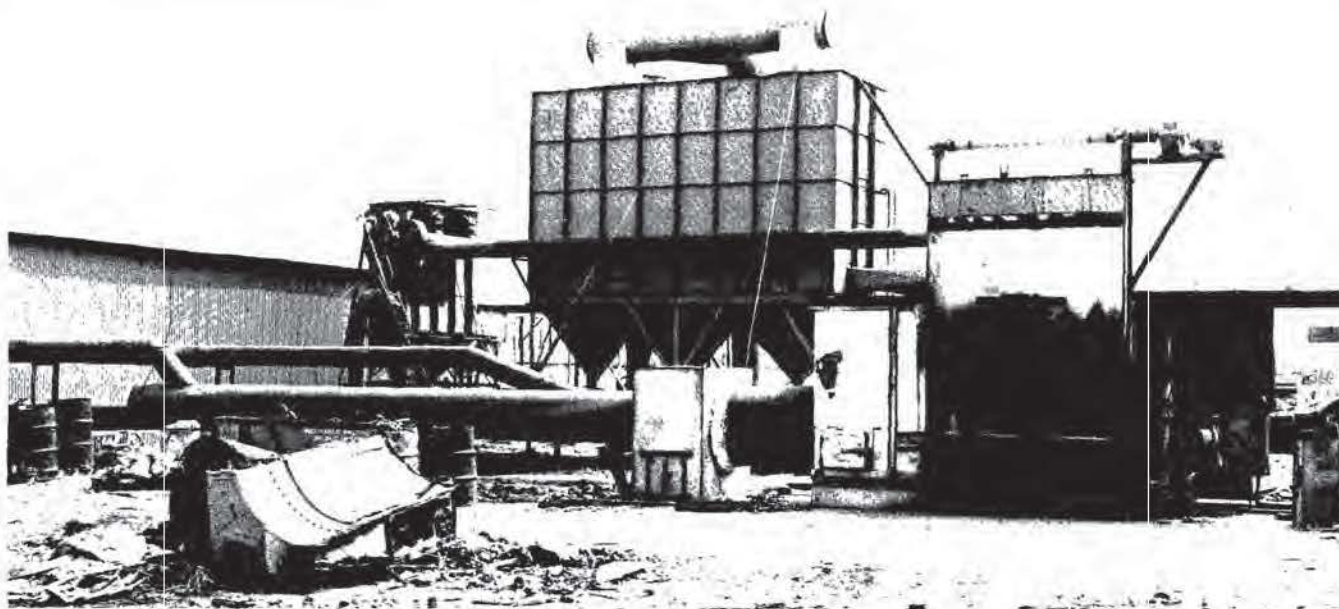
Figure 208. Aluminum-sweating furnace vented to an afterburner and baghouse (Du-Pol Enterprises, Los Angeles, Calif.).

Generally, emissions from core ovens are a minor source of air pollution when compared with other metallurgical processes. If the ovens are operated below 400°F and are fired with natural gas, emissions are usually tolerable. Nevertheless, there are instances, for example, when special core formulations are used, when emissions can have opacities exceeding legal limits permitted in Los Angeles County, and when emissions can be extremely irritating to the eye because of aldehydes and other oxidation products. In these cases, a control device is necessary, normally an afterburner.

TYPES OF OVENS

The various types of core ovens fall into the following five classes: Shelf ovens, drawer ovens, portable-rack ovens, car ovens, conveyor ovens.

Shelf ovens are probably the simplest form of core ovens. They are merely insulated steel boxes, divided into sections by shelves. Core plates carrying cores are placed directly on the shelves. When a door is opened, all or at least several shelves are exposed and a large amount of heat escapes from the oven chamber. Figure 209 shows a gas-fired shelf oven. The hot gases escaping during loading and unloading of the shelves not only waste heat but also create undesirable working conditions. Because of these undesirable characteristics, these ovens are generally limited to baking small cores, particularly in a small-core department where the investment in oven equipment must be kept at a minimum.

Shelf ovens have been replaced largely by the more efficient drawer oven. One type of drawer oven is shown in Figure 210. With these ovens, one or more drawers can be withdrawn for loading or unloading and, since the drawers are equipped with rear-closing plates, hot gases do not escape. Within the oven, the drawers are supported on rollers and, when withdrawn, the front end is supported by an overhead drawer-selector with an operating arrangement to permit engagement of any one or any combination of drawers.

These ovens are suitable for baking small- and medium-sized cores, but they are limited in the volume of cores that can be baked because of labor involved in transporting the cores from the core maker to the oven, placing them in the drawers, removing them from the drawers, and taking them to storage.

To overcome some of the handling of cores, portable rack ovens were developed. The core maker places his cores directly onto a rack, which, when filled, is put into the oven. After the baking, the rack is removed and taken to storage. A different, loaded rack can then be placed in the oven. Figure 211 shows an empty rack oven. Racks are designed not only to fit the oven but also to accommodate large or small cores. They can be transported by an overhead monorail or lift trucks, either manually or power operated.

For large cores, car ovens are generally used. These ovens are similar to rack ovens but larger

Table 88. DUST AND FUME EMISSIONS FROM
AN ALUMINUM-SWEATING FURNACE CONTROLLED BY
AN AFTERBURNER AND BAGHOUSE

Furnace data	
Type of furnace	Reverberatory with integral afterburner
Furnace hearth area	4 ft 7 in. W x 8 ft 10 in. L
Process weight, lb/hr	2,870
Material sweated	Scrap aluminum

Baghouse data	
Type of bags	Tubular
Filter material	Dacron
Filter area, ft^2	4,800
Filter velocity, fpm	2.16
Precleaner	Settling chamber

Dust and fume data	Settling chamber inlet	Furnace charge door hood	Baghouse outlet
Gas flow rate, scfm	1,360	5,580	8,850[a]
Average gas temperature, °F	350	204	150
Concentration, gr/scf	0.505	0.081	0.0077
Dust and fume emission, lb/hr	5.89	3.88	0.58
Particulate control efficiency, %			94.1

Orsat analysis at settling
chamber inlet, volume %

CO_2	6.8
O_2	8.6
CO	0.02
N_2	77.33
H_2O	7.25

Particle size analysis at bag-
house outlet, wt %

+60 mesh	85.9
-60 mesh	14.1

Particle size analysis of -60
mesh portion, wt %

0 to 2 μ	6.9
2 to 5 μ	32.4
5 to 10 μ	30.9
10 to 20 μ	17.7
20 to 40 μ	7.7
< 40 μ	4.4

Combustible carbon in particu-
late discharge, dry wt %

Settling chamber inlet	83.7
Furnace chamber door hood exit	67.3

[a]Volume is greater at the baghouse exit than at the inlet because of leakage.

and, instead of portable racks, cars riding on rails are used. The cores, being large and heavy, are generally loaded on the cars by crane. Tiered pallets are frequently used to facilitate car load-ing. Because of the size of the cores, most of a day is usually needed to load a car; therefore, baking is usually done overnight.

Conveyor ovens are used in foundries where a large volume of cores of approximately the same

size are baked. Of course, larger cores can also be baked by allowing them to make two or more passes through the oven.

Conveyor ovens have loading and unloading sta-tions, a heated section, and a cooling section. A horizontal-conveyor oven is shown in Figure 212. These ovens are generally located above
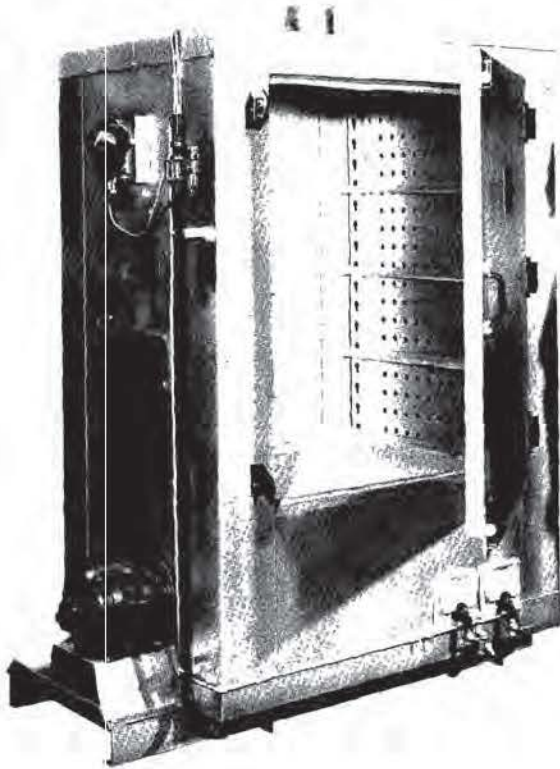
the floor level, in roof trusses, or above areaways between buildings. They have inclined entrances and exits to allow loading at the floor level and, probably more important, to provide natural-draft heat seals. The vertical-conveyor oven shown in Figure 213 requires little floor space for a large volume of baking. It is heated on the side where the cores enter the oven and throughout the top of the oven. With the use of baffles and a blower, the lower portion of the unloading side of the oven cools the baked cores. Core makers can be grouped around the loading side of the oven to minimize the handling of cores.

HEATING CORE OVENS

Probably the simplest and crudest method of heating core ovens is to use burners along the floor extending the entire length of the oven. These burners cannot be regulated automatically and they do not provide uniform heat throughout the oven. They can be dangerous, because of damping out of the flame at the back of an oven, which allows raw gas to accumulate resulting in explosions. Although a few ovens are still heated in this manner, most ovens use recirculating heater units.

With recirculating heaters, a portion of the oven gases is returned to the heater, and the rest is vented through a dampered stack to the atmosphere. Fresh air is mixed with the recirculated

Figure 209. Shelf oven (The Foundry Equipment Co., Cleveland, Ohio).
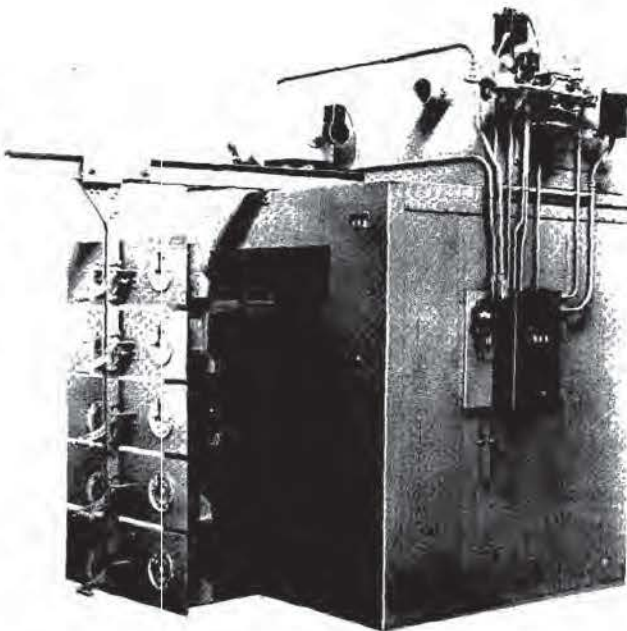
Figure 210. Drawer oven (Despatch Oven Co., Minneapolis, Minn.).

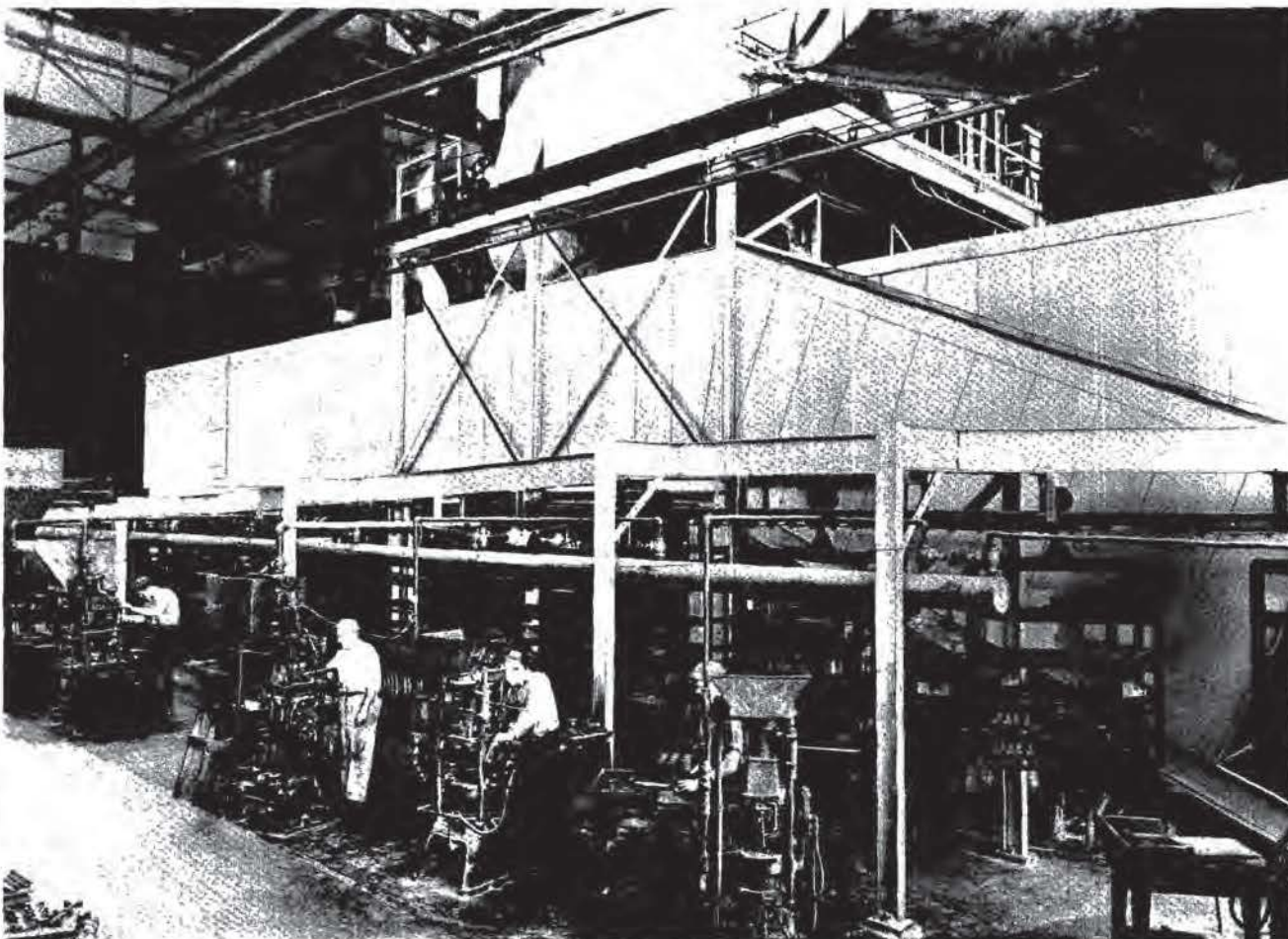Figure 211. Rack oven (Despatch Oven Co., Minneapolis, Minn.).

Figure 212. Horizontal, continuous oven (The Foundry Equipment Co., Cleveland, Ohio).

gases, and the mixture is heated. The hot gases and the products of combustion are blown into the oven. The amount of fresh air admitted is controlled by the amount of gases vented from the oven and only enough is admitted to supply the oxygen needed for the baking process.

CORE BINDERS

The primary reason for baking cores is to make them strong enough so that they can be handled while the mold is being made and so that they resist erosion and deformation by metal when the mold is being filled. The baking process drives off water and other volatiles, which reduces the total gas-forming material in the mold. Most of the "volatiles" discharged can be considered air contaminants. Their composition depends upon the type of binder used in the core.

Numerous binders require baking, but they do not all harden by the same chemical and physical processes. Based on their method of hardening, the binders can be subdivided into three types: (1) Those that harden upon heating, (2) those that

harden upon cooling after being heated, and (3) those that adhere upon heating. The binders of the first type develop their strength by chemical reaction, while those of the second and third types function through physical phenomena.

Pitch, rosin, and similar materials of type 2 are solids at room temperature, but upon heating, they melt and flow around the sand grains. When the mixture of sand and binder cools, the binder solidifies and holds the grains together. Those binders are frequently dissolved or dispersed in solvent and, when baked, the solvent is driven off, becoming an air contaminant.

The binders of type 3 are mixed with sand in the dry state. Water is then added and the binder becomes gelatinous, which imparts green strength to the mixture. Upon baking, these binders dehydrate, harden, and adhere to the sand grains holding them together. Since baking only drives water from the mixture, no air contaminants are created.

Type-1 binders harden by chemical action, partial oxidation, and polymerization. Drying oils,
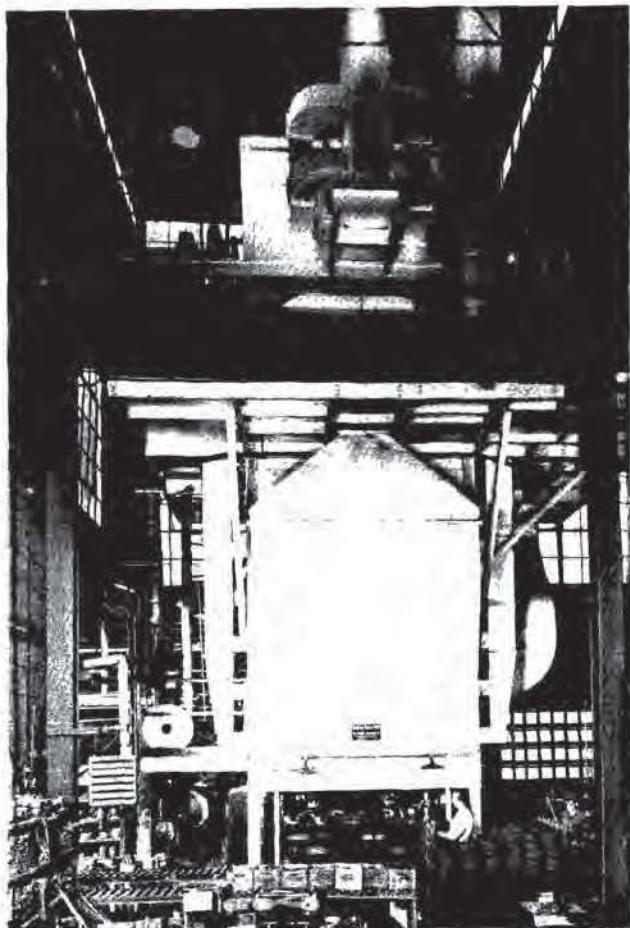
Figure 213. Vertical, continuous oven (The Foundry Equipment Co., Cleveland, Ohio).

of which linseed oil is typical, are made up of unsaturated hydrocarbons that are liquid at room temperature. Because they are unsaturated, the molecules can react with other molecules or elements without producing side products. These oils react with oxygen very slowly at room temperature and faster at elevated temperatures, to the extent that their unsaturation is partially satisfied, and then they polymerize to form a solid film that holds the sand grains together. If, however, too much heat is applied, the oxidation process goes too far and some molecules break up into lower molecular weight products instead of polymerizing. The result is a weaker film, and smoke, vapors, and gases are discharged.

The resin-type binders, such as phenol-formaldehyde, are intermediate, easily polymerized products of a phenol and formaldehyde condensation reaction. When heated, these compounds polymerize rapidly into a hard film. No side reactions should, however, occur; these substances, too, are organic and subject to burning if heated excessively.

In actual practice, cores seldom contain only one type of binder. A typical core mixture contains 930 pounds of sand, 7-1/2 pounds of core oil, 9 pounds of cereal binder, 3 pounds of kerosene, and 38 pounds of water. The core oil contains 45 percent linseed oil, 28 percent gum rosin, and 27 percent kerosene. All three types of binder are present. The linseed oil in the core oil is a type-1 binder and hardens by an oxidation-polymerization process. The gum rosin of the core oil is a type-2 binder and, after its solvents are driven off, it melts and then hardens when the cores are cooled. The cereal binder is corn flour, a type-3 binder, which is used to impart green strength to the core by its gelatinous reaction with water before the core is baked.

During the baking of these cores, a series of physical and chemical reactions occurs. First, the moisture and light fractions of the oil are distilled off. As the temperature rises, the heavier fractions of the kerosene are vaporized and the linseed oil begins to react with oxygen and to polymerize. At about 300°F, the rosin melts, coating the grains with a thin film of rosin.

The polymerization of the linseed oil requires more time than the physical changes that take place do, and so the core is held at a temperature of 375°F for 1-1/2 to 3-1/2 hours to develop maximum strength. A higher temperature accelerates the polymerization, but the danger of overbaking is also much greater. For instance, when linseed oil is baked at 375°F, its maximum strength is achieved in 1-1/2 hours, and its strength does not deteriorate if it is baked for 3-1/2 hours. At 400°F, a maximum strength, less than that achieved at 375°F, is reached in 3/4 hour, but the strength begins to deteriorate if the core is baked longer than 1-1/4 hours. And at 450°F, the maximum strength is reached in a little less than 3/4 hour and immediately begins to deteriorate if overbaked. Of course, since the entire body of the core cannot reach the oven temperature at the same time, if high temperatures are used the surface of the core is overbaked before the inner portions are completely baked. Moreover, the high temperatures tend to create smoke and objectionable gases that are discharged from the oven as air contaminants.

The resinous-type binders also have kerosene and cornflour added. Baking time and temperature requirements are, however, much less. In fact, high-frequency dielectric ovens can be used with the fast-setting synthetic resins. In these ovens, the electrical field created causes nonconductors within the field to become hot. The ovens generally have a relatively small heating space, through which a conveyor carries the cores. The conveyor is one of the electrodes; therefore, only the cores become heated. There are no hot gases

to contend with, and only the small amount of volatile materials in the cores are discharged. Baking time generally runs 2-1/2 minutes.

The Air Pollution Problem

The air contaminants discharged from core ovens consist of organic acids, aldehydes, hydrocarbon vapors, and smoke. The vapors are the result of the evaporation of hydrocarbon solvents, usually kerosene, and the light ends usually present in core oils. The organic acids, aldehydes, and smoke are the result of partial oxidation of the various organic materials in the cores. These substances have obnoxious odors and are very irritating to the eyes. The quantity and irritating quality of the oxidation products generally increase with an increase in baking temperature.

Emission rates, in general, are low, especially from small- and medium-sized ovens operating at 400°F or less. With some core binders, however, the emissions from small ovens operating at low temperatures can be of sufficient quantity to create a public nuisance. The emissions from larger ovens are generally greater and are more apt to create nuisances or be in excess of opacity regulations. Table 89 shows the amounts of various contaminants discharged from three core ovens. Test 1 shows the emissions from an uncontrolled oven, and tests 2 and 3 show the emissions from two ovens as well as the afterburners that control the emissions from them.

Excessive amounts of emissions can generally be expected from ovens operated at 500°F or higher, and from ovens in which the cores baked contain larger than normal amounts of kerosene, fuel oil, or core oils. Visible emissions are usually discharged from large conveyorized ovens. In many cases the opacity of these plumes has been in excess of Los Angeles County's opacity regulations.

Hooding and Ventilation Requirements

Most core ovens are vented directly to the atmosphere through a stack. The ovens require sufficient fresh air to be mixed with recirculated gases and with the products of combustion from the heater to keep the moisture content low and to supply the oxygen necessary for proper baking of the drying oil-type core binders.

Generally, the excess gases and any contaminants created are discharged from the oven through one vent stack. Occasionally more than one vent is used, but if the emissions are such that air pollution controls are needed, then ducting the vents to a control device is all that is necessary. The

Table 89. AIR CONTAMINANT EMISSIONS FROM CORE OVENS

Test No.	1	2		3	
Oven data					
Size	6 ft 2 in. W x 7 ft 11 in. H x 19 ft L	3 ft 10 in. W x 5 ft 3 in H x 18 ft L		4 ft 2 in. W x 6 ft 8 in. H x 5 ft 9 in. L	
Type	Direct gas-fired	Direct gas-fired		Indirect electric	
Operating temp, °F	380	400		400	
Core binders	1 to 1/2% phenolic resin	3% linseed oil		1% linseed oil	
Weight of cores baked, lb	700	1,600		600	
Baking time, hr	11	2-1/2 to 3		6	
Afterburner data					
Size		10 in. dia x 7 ft 6 in. H		3 ft dia x 4 ft H	
Type	None	Direct flame		Direct flame	
Burner capacity, Btu/hr		200,000		600,000	
Air contaminants from:	Oven	Oven	Afterburner	Oven	Afterburner
Effluent gas volume, scfm	100	140	260	250	440
Effluent gas temperature, °F	380	400	1,400	400	1,780
Particulate matter, lb/hr	0.13	0.2	0.013	0.27	0.02
Organic acids, lb/hr	0.068	0.008	0.000	0.44	0.087
Aldehydes, ppm	52	10	10	377	4
Hydrocarbons, ppm	124	-	< 10	158	< 19
Opacity, %	0	-	0	-	0
Odor	Slight	-	Slight	-	None

use of hoods or of excess air is not necessary to capture the emissions.

Air Pollution Control Equipment

As emphasized previously, when operated below 400°F and when fired with natural gas, most core ovens do not require air pollution control equipment. There have been, however, several cases where excessive emissions have been discharged and control equipment has been necessary.

Excessive emissions from core ovens have been reduced to tolerable amounts by modifying the composition of the core binders and lowering the baking temperatures. For instance, smoke of excessive opacity was discharging from an oven baking cores containing 3 percent fuel oil and 1.5 percent core oil at 500°F. The core binder was modified so that the cores contained 1.5 percent kerosene and 1.5 percent core oil, and the baking temperature was reduced to 400°F. After these modifications, no visible emissions were discharged from the oven.

When it is not feasible or possible to reduce excessive emissions from an oven by modifying the core mix or the baking temperature, afterburners are the only control devices that have proved effective. Since the quantity and concentration of the contaminants in the oven effluent are small, no precleaners or flashback devices are needed.

Afterburners that have been used for controlling the emissions from core ovens are predominantly of the direct-flame type. The burners are normally designed to be capable of reaching a temperature of at least 1,200°F under maximum load conditions. For most operations, 1,200°F completely controls all visible emissions and practically all odors.

The afterburner should be designed to have a maximum possible flame contact with the gases to be controlled and it should be of sufficient size to have a gas retention time of at least 0.3 second. Most authorities agree that the length-to-diameter ratio should be in the range of 1-1/2 to 4

In some instances, particularly on larger core ovens, catalytic afterburners have been used to control the emissions. With inlet temperatures of from 600° to 650°F all visible emissions and most of the odors were controlled. When catalytic afterburners are used, however, care must be taken to keep the catalyst in good condition; otherwise, partial oxidation can result in the discharge of combustion contaminants more objectionable than the oven effluent.

FOUNDRY SAND-HANDLING EQUIPMENT

A foundry sand-handling system consists of a device for separating the casting from the mold, and equipment for reconditioning the sand. The separating device is usually a mechanically vibrated grate called a shakeout. For small castings a manual shakeout may be used.

TYPES OF EQUIPMENT

The minimum equipment required for reconditioning the sand is a screen for removing oversize particles, and a mixer-muller where clay and water are combined with the sand to render it ready for remolding. In addition, equipment may be used to perform the following functions: Sand cooling, oversize crushing, fines removal, adherent coating removal, and conveying. A typical sand-handling system is shown in Figure 214.

Both flat-deck screens and revolving, cylindrical screens are used for coarse-particle removal. Revolving screens can be ventilated at such a rate as to remove excess fines.

Sand cooling can be accomplished in a number of ways, depending upon the cooling requirements. The amount of cooling required depends mainly upon the ratio of metal to sand in the molds and on the rate of re-use of the sand. With low metal-to-sand and re-use ratios, no specific sand-cooling equipment is required. When considerable cooling is required, a rotary drum-type cooler is usually used. A stream of air drawn through the cascading sand both cools and removes fines.

Oversize particles are hard agglomerates not broken up by the handling operations from the shakeout grate to the screen. Most of these are portions of baked cores. Many foundries discard the oversize particles, while others crush the agglomerates to recover the sand. A hammer- or screen-type mill is usually used for crushing.

Since molding sand is continuously reused, the grains become coated with a hard, adherent layer of clay and carbonaceous matter from the bonding materials used. In time the sand becomes unusable unless the coating is removed or a certain percentage of new sand is continuously added. Pneumatic reclamation is the method most widely used for coating removal. The sand is conveyed in a high-velocity airstream from a turbine-type blower and impinged on the inner surface of a conical target. Abrasion removes a portion of the coating material in each pass. The fines thus created are carried away in the airstream while the sand grains settle in an expansion chamber, as shown in Figure 215.

TO BAGHOUSE

ROTARY COOLER

SCREEN

SAND BIN

OVERSIZE CRUSHER

MEASURING HOPPER
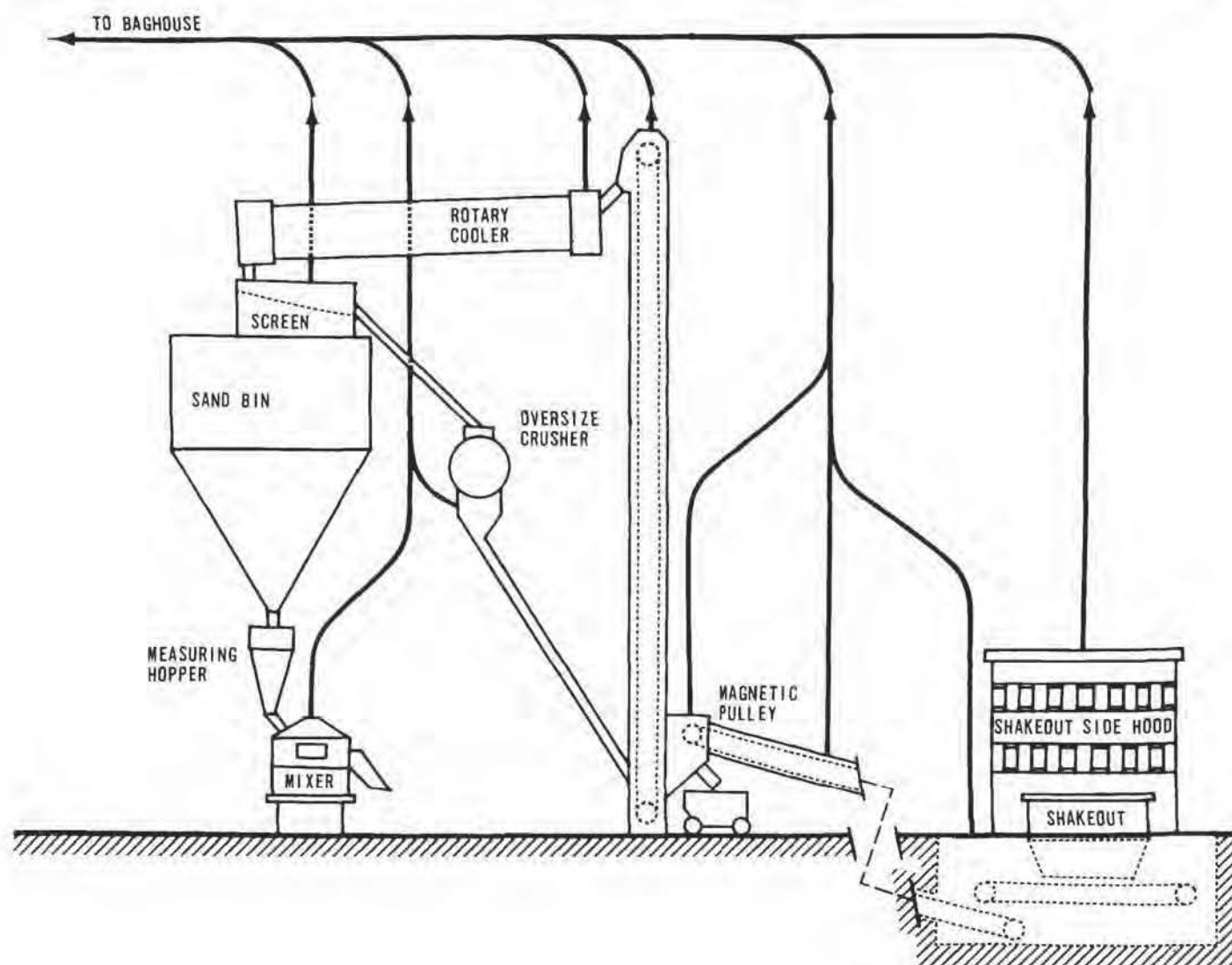
MIXER

MAGNETIC PULLEY

SHAKEOUT SIDE HOOD

SHAKEOUT

Figure 214. Typical foundry sand-handling system.

Foundry sand is usually conveyed by belt conveyors and bucket elevators, though pneumatic conveyors are used to some extent. Pneumatic conveying aids in cooling and fines removal.

The Air Pollution Problem

The air contaminants that may be emitted are dust from sand breakdown, and smoke and organic vapors from the decomposition of the core binders by the hot metal.

Among the factors that influence emission rates are size of casting, ratio of metal to sand, metal-pouring temperature, temperature of casting and sand at the shakeout, and handling methods. These factors have a great influence on the

magnitude of the air pollution problem. For instance, a steel foundry making large castings, with a high metal-to-sand ratio requires a very efficient control system to prevent excessive emissions. A nonferrous foundry making small castings with a low metal-to-sand ratio, on the other hand, may not require any controls, since the bulk of the sand remains damp and emissions are negligible.

Hooding and Ventilation Requirements

The need for ventilation is determined by the same factors that influence emission rates. Minimum volumes of ventilation air required to ensure the adequate collection of the air contaminants are indicated in the discussion that follows on the various emission sources.
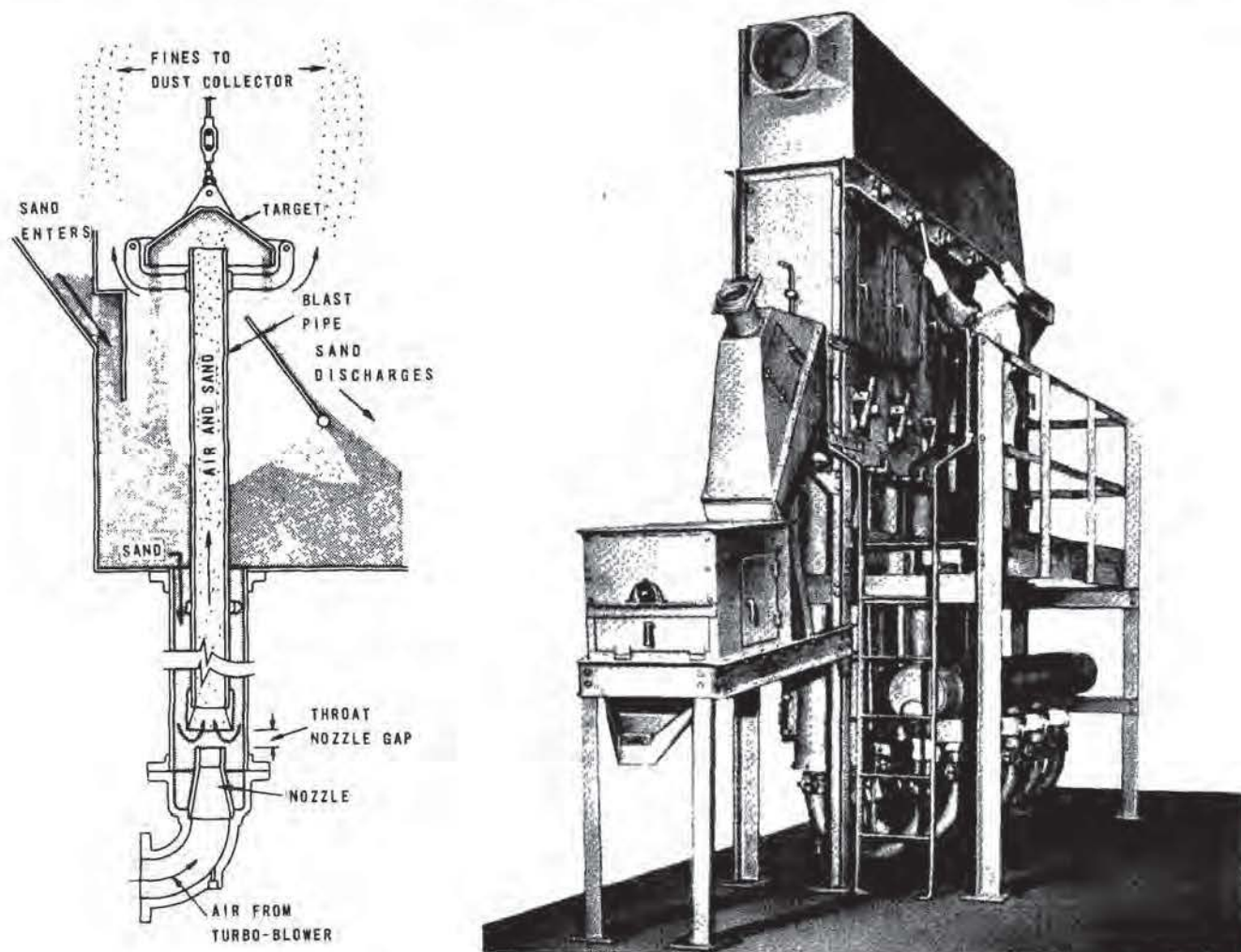
Figure 215. Pneumatic sand scrubber (National Engineering Co., Chicago, Ill.).

Shakeout grates

The amount of ventilation air required for a shakeout grate is determined largely by the type of hood or enclosure. The more nearly complete the enclosure, the less the required volume. When large flasks are handled by an overhead crane, an enclosing hood cannot be used, and a side or lateral hood is used instead. Recommended types of hood are shown in Figure 216 and Figure 217 (upper). Downdraft hoods are not recommended except for floor-dump type of operations where sand and castings are dropped from a roller conveyor to a gathering conveyor below the floor level (Manual of Exhaust Hood Designs, 1950). An excessive exhaust volume is required to achieve adequate control in a downdraft hood because the indraft velocity is working against the thermal bouyancy caused by the hot sand and casting. The indraft velocity is lowest where it is needed most--at the center of the grate. The exhaust volume requirements for the different types of hood are shown in Table 90. Shakeout hoppers should be exhausted with quantities of

about 10 percent of the total exhaust volume listed in this table.

Other sand-handling equipment

Recommended ventilation volumes and hooding procedure for bucket elevators and belt conveyors are given in Figure 218; for sand screens, in Figure 219; and for mixer-mullers, in Figure 220. The ventilation requirement for rotary coolers is 400 cfm per square foot of open area. For crushers the requirement varies from 500 to 1,000 cfm per square foot of enclosure opening.

Air Pollution Control Equipment

The most important contaminant to be collected is dust, though smoke is sometimes intense enough to constitute a problem. Organic vapors and gases are usually not emitted in sufficient quantities to be bothersome. The collectors usually used are baghouses and scrubbers.
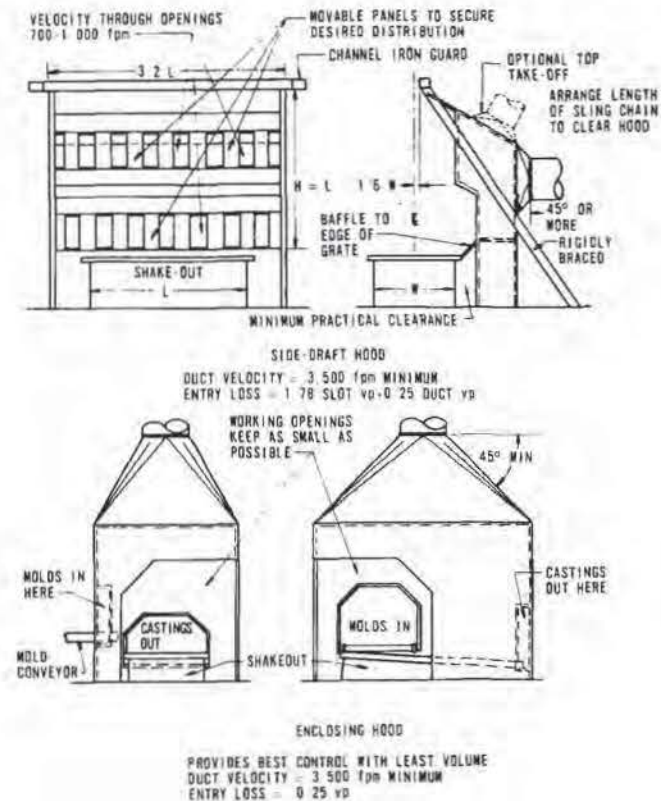
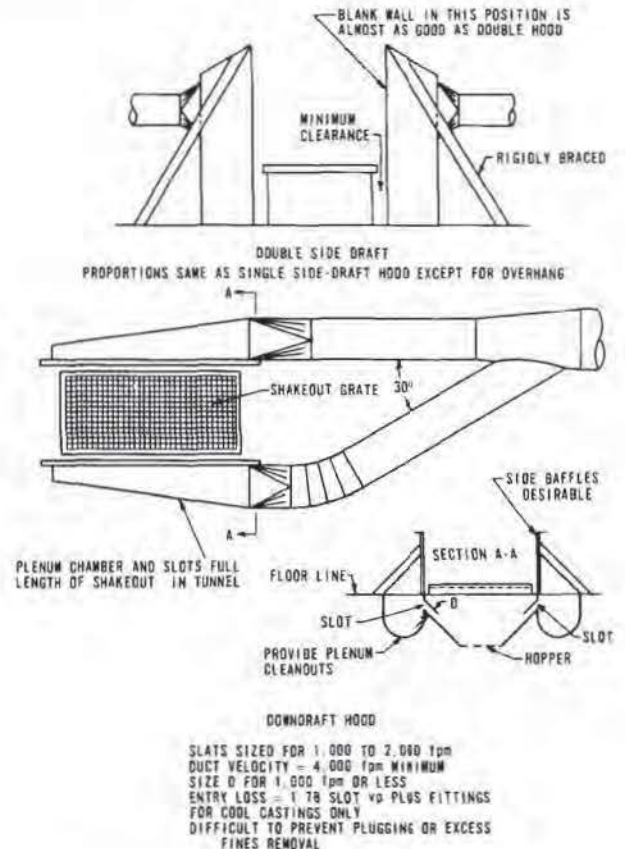Figure 216. Foundry shakeout (Committee on Industrial Ventilation, 1960).

Figure 217. Foundry shakeout (Committee on Industrial Ventilation, 1960).

Table 90. EXHAUST VOLUME REQUIREMENTS FOR
DIFFERENT TYPES OF HOOD
VENTILATING SHAKEOUT GRATES

Type of hood	Exhaust requirement[a]	
	Hot castings	Cool castings
Enclosing	200 cfm/ft^2 of opening. At least 200 cfm/ft^2 of grate area	200 cfm/ft^2 of opening. At least 150 cfm/ft^2 of grate area
Enclosed two sides and 1/3 of top area	300 cfm/ft^2 of grate area	275 cfm/ft^2 of grate area
Side hood (as shown or equivalent)	400 to 500 cfm/ft^2 of grate area	350 to 400 cfm/ft^2 of grate area
Double side hood	400 cfm/ft^2 of grate area	300 cfm/ft^2 of grate area
Downdraft	600 cfm/ft^2 of grate area Not recommended	200 to 250 cfm/ft^2 of grate area

[a] Choose higher values when (1) castings are very hot, (2) sand-to-metal ratio is low, (3) crossdrafts are high.
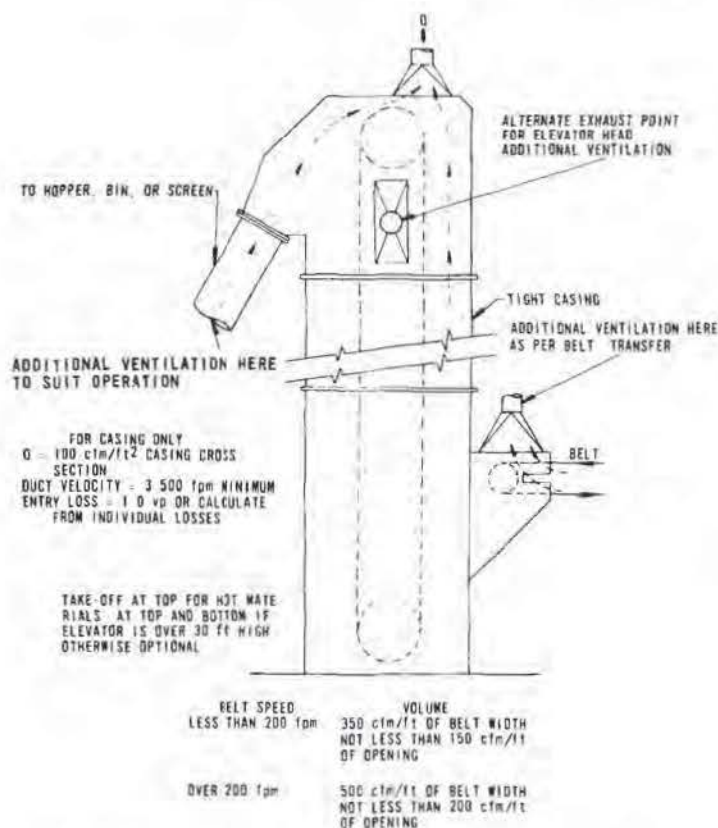
For casing only
Q = 100 cfm/ft² casing cross section
Duct velocity = 3,500 fpm minimum
Entry loss = 1.0 vp or calculate from individual losses

Take-off at top for hot materials. At top and bottom if elevator is over 30 ft high otherwise optional

Belt speed	Volume
Less than 200 fpm	350 cfm/ft of belt width not less than 150 cfm/ft of opening
Over 200 fpm	500 cfm/ft of belt width not less than 200 cfm/ft of opening

Figure 218. Bucket elevator ventilation (Committee on Industrial Ventilation, 1960).

FLAT DECK SCREEN
Q = 200 cfm/ft² through hood openings, but not less than 50 cfm/ft² screen area. No increase for multiple decks
Duct velocity = 3,500 fpm minimum
Entry loss = 0.5 vp

CYLINDRICAL SCREEN
Q = 100 cfm/ft² circular cross section of screen, at least 400 cfm/ft² of enclosure opening
Duct velocity = 3,500 fpm minimum
Entry loss = see "Flat deck screen"
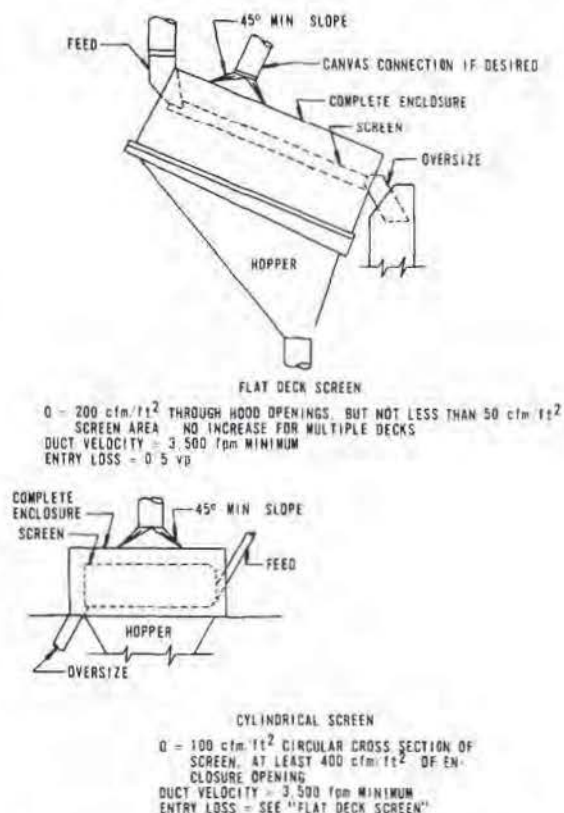
Figure 219. Screens (Committee on Industrial Ventilation, 1960).

Q = 150 cfm/ft² through all openings but not less than

Mixer diameter, ft	Exhaust, cfm
4	650
6	900
8	1,200
10	1,500

Duct velocity = 3,500 fpm minimum
Entry loss = 0.25 vp

NOTE: Other types of mixers, enclose as much as possible and provide 150 cfm/ft² of remaining openings
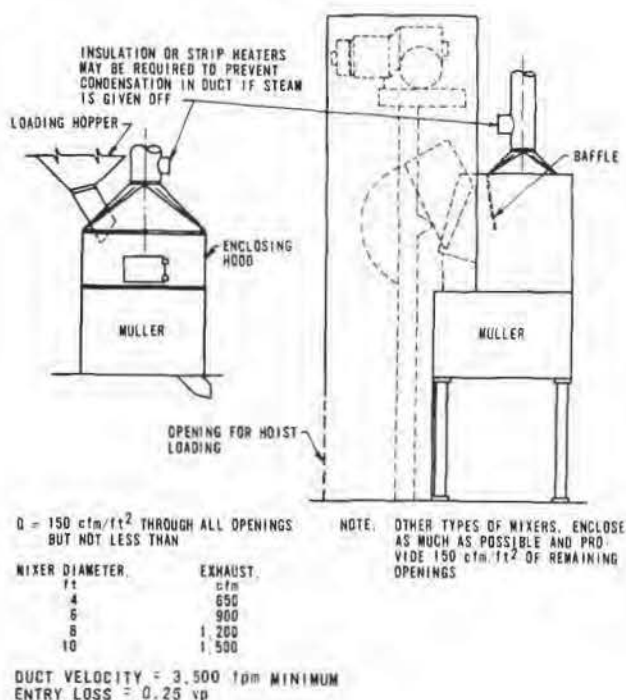
Figure 220. Mixer and muller hood (Committee on Industrial Ventilation, 1960)

A baghouse in good condition collects all the dust and most of the smoke. A scrubber of moderately good efficiency collects the bulk of the dust, but the very fine dust and the smoke are not collected and in many cases leave a distinctly visible plume, sufficient to violate some control regulations. A baghouse, therefore, is the preferred collector when the maximum control measures are desired.

When only the shakeout is vented to a separate collector, there may be sufficient moisture in the gases in some cases to cause condensation and consequent blinding of the bags in a baghouse. When, however, all the equipment in a sand-handling system is served by a single exhaust system, ample ambient air is drawn into the system to preclude any moisture problem in the baghouse. The filtering velocity for this type of service should not exceed 3 fpm. Cotton sateen cloth is adequate for this service. A noncompartmented-type baghouse is adequate for most job shop foundries. For continuous-production foundries, a compartmented baghouse with automatic bag-shaking mechanisms gives the most trouble-free performance.

HEAT TREATING SYSTEMS

Heat treating involves the carefully controlled heating and cooling of solid metals and alloys for effecting certain desired changes in their physical properties. At elevated temperatures, various phase changes such as grain growth, recrystallization, and diffusion or migration of atoms take place in solid metals and alloys. If sufficient time is allowed at the elevated temperature, the process goes on until equilibrium is reached and some stable form of the metal or alloy is obtained. If, however, because of sudden and abrupt cooling, time is not sufficient to achieve equilibrium at the elevated temperature, then some intermediate or metastable form of the metal or alloys is obtained. The tendency to assume a stable form is always present and metals and alloys in a metastable form can be made to approach their stable form as closely as desired simply by reheating. The widely differing properties that can be imparted to solid metals and alloys in their stable and metastable forms give purpose to the whole process of heat treating.

In general, the methods used to heat treat both ferrous and nonferrous metals are fundamentally similar. These methods include hardening, quenching, annealing, tempering, normalizing ferrous metals, and refining grain of nonferrous metals. Also included in the category of heat treating are the various methods of case hardening steels by carburizing, cyaniding, nitriding, flame hardening, induction hardening, carbonitriding, siliconizing, and so forth.

HEAT TREATING EQUIPMENT

Furnaces or ovens, atmosphere generators, and quench tanks or spray tanks are representative of the equipment used for heat treating.

Furnaces for heat treating are of all sizes and shapes depending upon the temperature needed and upon the dimensions and the number of pieces to be treated. A furnace may be designed to operate continuously or batchwise. The controls may be either automatic or manual. These furnaces are known by descriptive names such as box, oven, pit, pot, rotary, tunnel, muffle, and others. Regardless of the name, they all have the following features in common: A steel outer shell, a refractory lining, a combustion or heating system, and a heavy door (either cast iron or reinforced steel with refractory lining) that may be opened from the top, the front, or from both the front and the back.

Atmosphere generators are used to supply a controlled environment inside the heat treating chamber of the furnace. The atmosphere needed may be either oxidizing, reducing, or neutral depending upon the particular metal or alloy undergoing heat treatment and upon the final physical properties desired in the metal or alloy after treatment. An atmosphere can be provided that will protect the surface of the metal during heat treatment so that subsequent cleaning and buffing of the part is minimized, or one can be provided that will cause the surface of the metal to be alloyed by diffusion with certain selected elements in order to alter the physical properties of the metal.

Quench tanks may be as simple as a tub of water or as elaborate as a well-engineered vessel equipped with properly designed means to circulate the quenching fluid and maintain the fluid at the correct temperature. The part to be quenched is either immersed into the fluid or is subjected to a spray that is dashed against the part so that no air or steam bubbles can remain attached to the hot metal and thereby cause soft spots. The fluid used for quenching may be water, oil, molten salt, liquid air, brine solution, and so forth. The purpose of quenching is to retain some metastable form of an alloy (pure metals are not affected by quenching) by rapidly cooling the alloy to some temperature below the transformation temperature.

The Air Pollution Problem

The heat treating process is currently regarded as only a minor source of air pollution. Nonetheless, air pollutants that may be emitted from heat treating operations, and their origin, are as follows:

1.　Smoke and products of incomplete combustion arising from the improper operation of a gas- or oil-fired combustion system;

2.　vapors and fumes emanating from the volatilization of organic material on the metal parts being heat treated;

3.　oil mists and fumes issuing from oil quenching baths (if water-soluble oils are used, the fumes will be a combination of steam and oil mist);

4.　salt fumes emitted from molten salt pot furnaces;

5.　gases, produced by atmosphere generators, used in the heat treating chamber of muffle furnaces. (Insignificant amounts occasionally leak out from some furnace openings that cannot be sealed, but somewhat larger amounts get into the surrounding air during purging and also during loading and unloading operations.)

Hooding and Ventilation Requirements

Hooding and ventilation systems designed for heat treating processes should be based on the rate at which the hot, contaminated air is delivered to the receiving face of the exhaust hood. To prevent the hot, contaminated air from spilling out around the edges of the exhaust hood, the rate at which the exhaust system draws in air must in all cases exceed the rate at which the hot, contaminated air is delivered to the exhaust system.

In the general case, a canopy hood mounted about 3 or 4 feet above a hot body has an excellent chance of capturing all the hot, contaminated air rising by convection from the hot body. The face area of a canopy hood such as this should be slightly larger than the maximum cross-sectional area of the hot body. In order to avoid the need for excessive exhaust capacity, it is advisable not to oversize the canopy hood face area.

If a canopy hood is mounted too high above the hot body, the column of hot, contaminated air is influenced by turbulence, and the column becomes more and more dilute by mixing with the surrounding air. Consequently the exhaust capacity must be sufficient to handle this entire volume of diluted, contaminated air. This is an inefficient way to collect hot, contaminated air.

Many variations of canopy hoods are used because of the many types of heat treating furnaces employed. Lateral-type hoods are also used. General features of design of hoods for these hot processes are discussed in Chapter 3.

Air Pollution Control Equipment

The following methods effectively prevent and control emissions resulting from heat treating operations.

1. Proper selection of furnace burners and fuels along with observance of correct operating procedures will eliminate smoke and products of incomplete combustion as a source of air pollution. (See Chapter 9.)

2. Removal of organic material adhering to metal parts to be heat treated by either steam cleaning or solvent degreasing before heat treating will eliminate this source of air pollution.

3. Mists and fumes issuing from oil quenching baths can be greatly reduced by selecting appropriate oils and by adequate cooling of the oil.

4. Baghouses are a satisfactory method of controlling salt fumes from molten salt pots. Particle sizes of fumes are usually between 0.2 and 2 microns but may vary from this range depending upon local factors such as temperature, humidity, turbulence, and agglomeration tendencies of the effluent. The fumes are slightly hygroscopic and corrosive; therefore, operation of the baghouse must be continuous to prevent blinding and deterioration of the bag cloth and corrosion of the metal structure. Acrylic-treated orlon is a satisfactory bag cloth because of its chemical and thermal resistance and its general physical stability. Filtering velocities should not be greater than 3 fpm. With these design features, collection efficiencies exceeding 95 percent are normally achieved.

5. Flame curtains placed at the open ends of continuous heat treating furnaces are effective in the control of any escaping, combustible gases used for controlling the atmosphere inside the furnace.